Cleanroom Energy Benchmarking and Efficiency Technology Transfer Assistance Site Report

Facility I

Southern California

June 2004

Sponsored By:

Lawrence Berkeley National Laboratory

Prepared By:

Rumsey Engineers, Inc
99 Linden Street
Oakland, CA 94607
www.RumseyEngineers.com

Acknowledgements

Special thanks to the entire facilities staff for their generous assistance and cooperation throughout the benchmarking process.

Project Team

Lawrence Berkeley National Laboratory	**Rumsey Engineers, Inc**
Bill Tschudi	Peter Rumsey
Dale Sartor	Achai Broner
	Larry Chu
	John Weale

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I. EXECUTIVE SUMMARY

As part of the California Energy Commission PIER study, energy use at Facility I was monitored March 15 to March 23, 2004. Facility I, built approximately two years ago, is a facility that houses primarily cleanrooms, office spaces, and non-clean laboratory and manufacturing areas.

This site report reviews the data collected by the monitoring team and presents a set of performance metrics as well as a complete set of trended data points for the end uses of energy for equipment supporting and located in the cleanrooms. Some of the most important metrics are summarized below in Tables 1 and 2.

Table 1. Cleanroom Metric Results for Facility I

Metric Name	Metric Value
Class 100 Recirculation Fan Efficiency	1,655 cfm/kW
Class 100 Make Up Fan Efficiency	995 cfm/kW
Class 10,000 Recirculation Fan Efficiency	1,756 cfm/kW
Class 10,000 Make Up Fan Efficiency	1,000 cfm/kW

Table 2. Chilled Water System Metric Results for Facility I

Metric Name	Metric Value
Chiller Efficiency	0.96 kW/ton
Chilled Water Pumps Efficiency	0.06 kW/ton
Total Chilled Water System Efficiency	1.06 kW/ton
Process Chiller Efficiency	1.52 KW/ton

These efficiency numbers are averages of 1-minute samples. Data was taken for the chiller over a period of 6 days (March 18 through March 23, 2004) when all the equipment was running and monitored simultaneously. Data for the process chiller was taken over a period of 3 days (March 18 through March 20, 2004). See Appendix B for charts of the trended data.

The metrics for the HVAC systems at Facility I show that there are opportunities for energy efficiency. The values in Table 2 indicate that the chillers have poor efficiency. However, air-cooled chillers are inherently not very energy efficient.

The monitoring team observed a number of opportunities for potential energy savings at the facility. A summary of these observations follows and a more detailed discussion can be found in Section VI “Site Observations Regarding Energy Efficiency”.

II. INTRODUCTION

Energy metrics were established that allow cleanroom owners to evaluate their energy efficiency performance and identify opportunities for improvements that reduce their overall operating costs. The project is administered by LBNL and funded through the California Energy Commission.

With this report, Facility I is receiving the energy monitoring data collected at its facilities as a service provided by LBNL to participants in this project. This Site Report summarizes the data collected and presents energy performance metrics with which the facility can evaluate the performance of its cleanrooms. First, the report reviews the site characteristics, noting design features of the mechanical plant and the cleanrooms monitored. Second, the energy use for the cleanrooms and major mechanical equipment is broken down into major components. Third, performance metrics recorded through the project are presented. Finally, key energy efficiency observations for the facility will be noted. The data collected, trended graphs and methodology documentation are included among the appendices.

III. REVIEW OF SITE CHARACTERISTICS

A. Site

Facility I, located in Southern California, is a two-story 69,310 sf building that is approximately two years old and situated on a 151,200 sf lot. The building houses primarily cleanrooms, office spaces, and non-clean laboratory and manufacturing areas. The building is broken down as follows: cleanroom areas account for 15,430 sf (22%); office areas occupy 20,800 sf (30%); non-clean laboratory and manufacturing areas are 12,340 sf (18%); the second floor equipment area also referred to as the mezzanine, and the corridors/miscellaneous areas account for 20,750 sf (30%).

A 1000 kVA/800 kW diesel generator provides backup power in the case of a utility failure. Backup power is supplied to the recirculation air handlers, exhaust fans and lighting for life safety reasons, various process tools, and the fire alarm and telephone systems. Uninterruptible power supply (UPS) systems, the largest rated for 120 kW, are also utilized to provide emergency power to additional process tools located in the cleanrooms.

The majority of employees work from 8AM to 5PM, Monday through Friday, although the environmental systems serving the cleanrooms run 8,760 hours a year in order to maintain conditions. However, during the non-working periods, the make up and recirculation air handlers serving the cleanrooms are set to provide less airflow, and thus run at a lower fan speed. Since people, being the main source of contaminants in a cleanroom, are not present, less air is required to maintain cleanliness. As a result, fan energy and cooling/heating energy are lowered during the non-working hours.

The cleanroom spaces are conditioned by a chilled water plant, hot water boiler plant, and electric humidifiers. A VAV (variable air volume) system consisting of two large rooftop air handlers serves the non-clean laboratory areas. The office areas are conditioned by rooftop package units. Chilled water is provided by three air-cooled chillers to the make up air handlers (MUAH). Hot water is provided by three hot water boilers to the hot water coils in the make up air handlers, the reheat coils in the return ducts of the recirculation air units, and to the VAV boxes serving the laboratory areas. A separate air-cooled chiller is utilized to supply process cooling for the cleanroom and non-clean manufacturing/laboratories' process tools. Deionized (DI) water, process vacuum, and compressed air also are generated for use in the cleanrooms.

The cleanrooms chosen for monitoring are the MBE/Metal/Junction Formation Cleanrooms (3,660 sf), and the Hybridization/Micro-Optics/ONM Array Production/Bonding Assembly Cleanrooms (4,310 sf).

The MBE/Metal/Junction Formation Cleanrooms are class 100. Although there are walls of separation between these cleanrooms, they were grouped together for this study since they are served by the same make up and recirculation air handling units (RCU). The Hybridization/Micro-Optics/ONM Array Production Assembly/Bonding Cleanrooms are the only class 10,000 cleanrooms in this facility. The remainder of the cleanrooms are class 100 and account for 7,460 sf of this building.

Chiller

Chilled water is produced by three 170 ton air-cooled chillers connected by a common header. Normally, two chillers run with one on emergency backup. The chilled water system employs a primary only loop pumping system. There are three variable-speed driven pumps; two normally operate with one on emergency backup. The pumps supply the chilled water to the make up air handlers only. During the monitoring period, primary chilled water was supplied at 40.8 ± 2.7°F.

Over the chiller monitoring period from March 18, 2004 through March 23, 2004 the outside air temperature ranged from 53°F to 72°F (see Appendix B for trended data). During that time two chillers operated at a combined average load of 201 tons with an overall range from 73 to 328 tons.

There are three 1,530 MBH boilers, with one on emergency backup, used to generate hot water for use in the hot water coils of the make up air handlers. Hot water is also used for reheat coils located in the ductwork of the recirculation air handlers, and in the VAV reheat coils serving the laboratory and manufacturing spaces. Hot water is distributed by one hot water pump with an additional pump serving as an emergency backup.

Process Cooling Water Pumps

Process cooling water is supplied by a 50 ton air-cooled chiller coupled to two variable-speed driven pumps and a storage tank. One pump normally runs with the other on emergency backup to cool the process tools located in the cleanrooms, and in the manufacturing and laboratory areas. The storage tank provides backup cooling in the event of an emergency. When there is a power failure, chilled water in the tank continues to be distributed by the pump connected to the backup generator to the tools without the operation of the process cooling chiller. Over the process cooling chiller monitoring period from March 18 through March 23, 2004, the process cooling water supply temperature was 62.9 ± 2.1°F.

Compressed air and DI water are produced at the central location for use in the cleanrooms. There are several small, individual process vacuum pumps dispersed throughout the cleanrooms. The cleanrooms are equipped with exhaust fans; no air scrubbers are fitted. Corrosives, solvents and non-contaminated air are exhausted from various cleanrooms.

B. MBE/Metal/Junction Formation Cleanroom Design

The MBE/Metal/Junction Formation Cleanrooms as measured in this report is a total of 3,660 sf, including both primary and secondary (air return) areas. See the table below for a breakdown of the areas. The cleanrooms utilize ducted HEPAs and are rated at class 100. HEPA ceiling coverage in the cleanrooms is 100%. The MBE cleanroom has low sidewall returns. The Metal cleanroom utilizes a combination of a low sidewall return and service chase for the return air. The Junction Formation cleanroom is a raised floor cleanroom with a service chase for return air. The service chases are class 100,000 rated and house the tools used to support the production in the Metal and Junction Formation Cleanrooms.

Table 3. Class 100 Cleanroom Areas

Cleanroom	Primary Area (sf)	Secondary Area (sf)	Total Area (sf)
MBE	565	150	715
Metal	655	695	1,350
Junction Formation	1,085	510	1,595
Total	2,305	1,355	3,660

The MBE/Metal/Junction Formation Cleanrooms are served by one make up air handler (AHU-2), and two recirculation air handlers (RAH-3 and RAH-4). The make up unit delivers its air to the intake plenums of the RCUs. The make up air handler is served with chilled water and heating hot water. In the return ducts of the recirculation air handlers are hot water coils and electric humidifiers. The electric humidifiers are supplied with deionized water. There are 2 general exhaust fans that serve the cleanroom; they exhaust directly to the outdoors without a scrubber.

Recirculation Air Handler Unit, RAH-3

During non-working hours in the cleanrooms, the make up and recirculation air handler fans are turned down to supply a lower amount of airflow to a point where cleanliness continues to be maintained. Since people being the major source of contaminants in a cleanroom are not present, this allows for lower airflows in the cleanroom, thus lower fan and heating/cooling energy are consumed. During the monitoring period, the two RCUs were operating at a combined power of 124.1 kW during normal working hours. During the turndown mode, the RCUs were consuming about 72% less power (34.2 kW) than in the normal operating mode. The MUAH airflow was not turned down during the monitoring period due to a failed VFD.

The condition specifications for the cleanrooms are 69°F ± 2°F and 45% ± 10% relative humidity. During the monitoring period, the measured temperature for the MBE Cleanroom was 66°F ± 2°F, and the average measured relative humidity was 48% with a fluctuation of ± 6%; the measured temperature for the Junction Formation Cleanroom was 67°F ± 1°F, and the average measured relative humidity was 48% with a fluctuation of ± 4%. The cleanroom temperature and humidity sensors may need to be calibrated.

C. Hybridization/Micro-Optics/ONM Array Production Assembly/Bonding Cleanroom Design

Make Up Air Handler, AHU-3

The Hybridization/MicroOptics/ ONM Array Production Assembly/ Bonding Cleanrooms are class 10,000 ducted HEPA cleanrooms with 25% filter coverage. The total cleanroom area, including both primary and secondary areas, is 4,310 sf. Most of the investigated cleanrooms are open to one another, except for the Bonding Cleanroom which has its own physical walls of separation. Although, this cleanroom does share a common low sidewall return air space with the other cleanrooms. The class 10,000 cleanrooms are served by a single make up air handler (AHU-3) and one recirculation air handler (RAH-6). The make up unit delivers its air to the intake plenum of the RCU. The cleanroom return air is directed through low sidewall returns around the perimeter of each of the cleanrooms.

Table 4. Class 10,000 Cleanroom Areas

Cleanroom	Primary Area (sf)	Secondary Area (sf)	Total Area (sf)
Hybridization	1,500	190	1,690
Micro-Optics	1,120	145	1,265
ONM Array Production Assembly	645	120	765
Bonding	280	70	350
Cleanroom Entry	205	35	240
Total	3,750	560	4,310

The make up air handler is served with chilled water, and heating hot water. In the return ducts of the recirculation air handler are hot water coils and electric humidifiers. The electric humidifiers are supplied with deionized water.

During non-working hours in the cleanrooms, the make up and recirculation air handler fans are turned down to supply a lower amount of airflow to a point where cleanliness continues to be maintained. Since people being the major source of contaminants in a cleanroom are not present, this allows for lower airflows in the cleanroom, thus lower fan and heating/cooling energy are consumed. During the monitoring period, the RCU and the MUAH were operating at a 22.9 kW and 13.7 kW, respectively during normal working hours. During the turndown mode, the RCU was consuming about 62% less power (8.7 kW) than in the normal operating mode. The MUAH was consuming 81% less power (2.6 kW) during the turndown mode.

The design specifications for the cleanroom air conditions are 69°F ± 2°F and 45% ± 15% relative humidity. During the monitoring period, the measured temperature was 66°F ± 2°F, and the measured relative humidity was 51% ± 8%. The cleanroom temperature and humidity sensors may need to be calibrated.

Table 5. Summary of Measured Cleanroom Air Handling Parameters

Description		***MBE/Metal/ Junction Formation***	***Hybridization/Micro-Optics/ONM Array Production Assembly/ Bonding***
		Class 100	*Class 10,000*
Primary Area	sf	2,305	2,570
Ceiling Height	ft	9	9
Total Make Up Air [1]	cfm	40,000	13,750
Total Make Up Fan Power [2]	kW	40.2	13.7
Total Recirculation Air [1]	cfm	205,330	40,260
Total Recirculation Fan Power [2]	kW	124.1	22.9
Room Air Changes per Hour	ACH	594	72
HEPA Filter Ceiling Coverage	%	100	14
Average Ceiling Filter Velocity [3]	fpm	105	90

1. *Make Up and Recirculation Air is the air delivered, based on the balance report data.*
2. *Make Up and Recirculation fan power reported for cleanrooms in normal operating mode.*
3. *Filter velocity based on average filter flow and 6.8 sf (85%) effective filter area.*

IV. SITE ENERGY USE CHARACTERISTICS

A. Site Energy Use

Facility I paid over $1 million in calendar year 2003 for energy use; Table 6 gives a breakdown. Table 7 calculates two key values to use in comparing the facility to other facilities with similar operations. Facility I pays average rates of $0.121/kWh for electricity and $0.64/therm for natural gas.

Table 6. Annual Energy Use

Annual Electricity Usage (MWh/yr)	Annual Electricity Cost ($/yr)	Annual Natural Gas Usage (therms/yr)	Annual Natural Gas Cost ($/yr)	Annual Total Cost ($/yr)
8,260	999,900	119,900	77,000	1,076,900

Source: Power bills for the year 2003.

Table 7. Annual Energy Utilization Intensity (EUI) and Energy Cost per Square Foot

Area (sf)	Energy Utilization Intensity (kWh/sf·yr)	Annual Energy Cost per Square Foot ($/sf·yr)
69,310	170	15.5

Energy from natural gas has been converted to kWh for the EUI calculation.

B. Cleanroom Power Consumption

The energy consumption attributed to the cleanroom air handling systems, exhaust fans, process tools, and lighting are reported in Tables 8 and 9. This breakdown of energy use by equipment helps identify the major loads.

This cleanroom has a relatively low process load and typically high HVAC power requirements. The HVAC power usage actually exceeds the process power usage by a factor of 6 for the class 100 cleanrooms, and by a factor of 3 for the class 10,000 cleanrooms.

Table 8. MBE/Metal/Junction Formation Cleanroom Power Consumption Breakdown

Description	Average Load (kW)	Average Efficiency
AIR HANDLING [1]		
Make Up Fan	40.2	995 cfm/kW
Recirculation Fans	124.1	1,655 cfm/kW
EXHAUST FANS		
EF-8A & 8B (Strobic Air)	23.3	888 cfm/kW
EF-13	1.8	1,944 cfm/kW
EF-15	0.4	1,579 cfm/kW
PROCESS	20.3	N/A
LIGHTS	4.2	N/A

1. *Make Up and Recirculation Fan power reported for cleanrooms in normal operating mode.*

Table 9. Hybridization/Micro-Optics/ONM Array Production Assembly/Bonding Cleanroom Power Consumption Breakdown

Description	Average Load (kW)	Average Efficiency (cfm/kW)
AIR HANDLING [1]		
Make Up Fan	13.7	1,000 cfm/kW
Recirculation Fan	22.9	1,756 cfm/kW
EXHAUST FANS		
EF-18	0.47	1,702 cfm/kW
PROCESS	6.9	N/A
LIGHTS	6.1	N/A

1. *Make Up and Recirculation fan power reported for cleanrooms in normal operating mode.*

C. Major Mechanical and Electrical Systems Power Consumption

The table below shows the power consumption of the chiller system for space cooling, process cooling chiller system, the emergency generator standby, and the UPS. The 1000kVA/800 kW emergency generator constantly draws power to maintain the oil temperature in the motors that drive the generator. The UPS has a capacity of 120 kW and was loaded at 36%.

Table 10. Energy Use by Major Components

Description	Average Load (kW)	Average Efficiency
COOLING SYSTEMS		
Chillers	195.5	0.96 kW/ton
Chilled Water Pumps	12.4	0.06 kW/ton
Process Cooling Chiller	21.8	1.52 kW/ton
Process Cooling Water Pump	7.8	-
ELECTRICAL SYSTEMS		
Emergency Generator Standby Power	1.73	N/A
UPS		
Input Power	43.3	86%
Output Power	37.3	

D. Recirculation Air System Setback

The recirculation air handling system uses an innovative reset to save power. When the cleanroom is not in use, there are many fewer sources of particles in the space. As evidenced by the facilities high gowning protocols, the site designer and operators are well aware that the human operators are the primary source of containments in the cleanroom space. The design intent of recirculation airflow is to continuously sweep particles from the space and remove them via the ceiling HEPA filters. With the recognition of people in the spaces as the primary source of particles, it is natural to connect the recirculation airflow quantities with the number of people, particle sources, in the space. Facility I has made this connection and implemented an off-shift airflow setback with excellent results. The following figure shows the fan power of a recirculation unit for a Friday through Monday period.

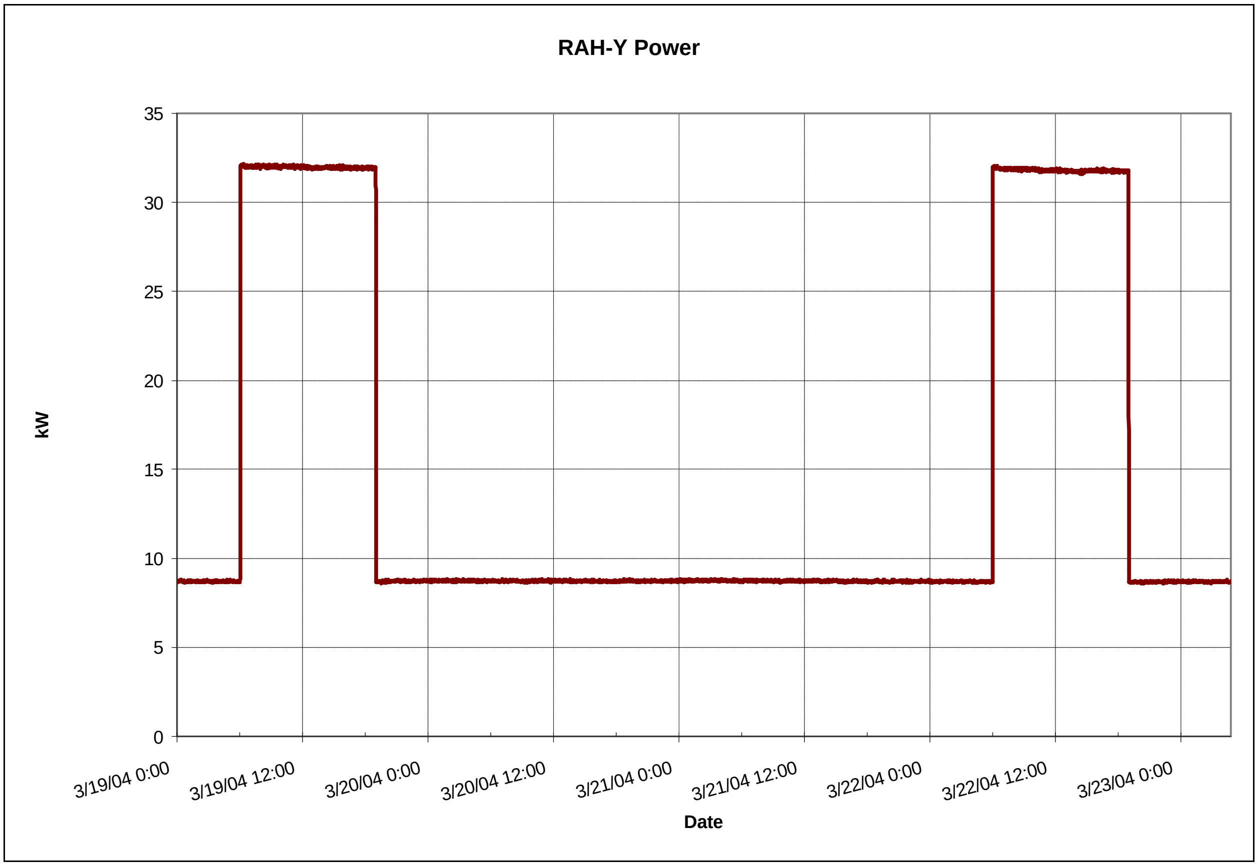


Figure 1. Recirculation Air Handler Power (One Minute True RMS Power Log)

While the airflow is setback less than 40% from the full occupied airflow, the actual measured power savings exceed 70%. Note that the power savings are measured values and do not follow the fan power 'laws' exactly. The power reduction results in significant real world energy savings, as summarized in the table below. This very simple energy efficiency measure is achieving significant savings with no impact on the facility operation.

Table 11. Recirculation Air System – Setback Metrics and Savings

Description		***MBE/Metal/ Junction Formation Cleanrooms***	***Hybridization/Micro-Optics/ONM Array Production Assembly/ Bonding Cleanrooms***
		Class 100	*Class 10,000*
Recirculation Air Power, Setback	kW	34.2	8.7
Recirculation Air Handler Volume, Setback [1]	cfm	128,000	28,000
Recirculation Air Setback Efficiency	cfm/kW	3,740	3,200
Recirculation Air Changes per Hour, Setback	ACH	371	50
Sitewide Savings			
Recirculation Air Annual Energy Savings [2]	kWh	1,250,000	
Recirculation Air Annual Cost Savings [2]	$/yr	138,000	

1. *Estimated using fan laws to scale flow and measured power data.*
2. *Extrapolated out to full site to include 3 identical but unmeasured recirculation units, $0.11/kWh average assumed.*

V. SYSTEM PERFORMANCE METRICS

Metrics are ratios of important performance parameters that can characterize the effectiveness of a system or component. In order to gage the efficiency of the entire building system design and operation, this project tracks key metrics at different system levels. These metrics can be used to compare designs or determine areas with the most potential for improvement via retrofit or replacement.

MBE/Metal/Junction Formation Cleanrooms & Hybridization/Micro-Optics/ONM Array Production Assembly/Bonding Cleanrooms

For Facility I, the cleanroom HVAC components operate at a nearly constant level throughout the year. Therefore, these metrics are based on spot measurements. All of the metrics involving area are based on the primary cleanroom area, which is the area that passes certification, unless otherwise noted.

The MBE/Metal/Junction Formation Cleanrooms are class 100. The ducted HEPA recirculation air handling efficiency was 1,655 cfm/kW. The recirculation air handling efficiency is average, when compared to other class 100, ducted HEPA cleanroom facilities with efficiencies ranging from 1,090 – 2,210 cfm/kW.

The class 10,000 cleanrooms also utilize a ducted HEPA design. The recirculation air handler efficiency is slightly better when compared to another class 10,000 ducted HEPA cleanroom facility with an efficiency of 1,635 cfm/sf. However, the RCU efficiency at this site is average when compared to the recirculation air handler efficiency between all tested facilities of various class ratings (see Figure 2 below).

The make up air handler efficiency for the class 100 and class 10,000 cleanrooms was 995 cfm/kW and 1,000 cfm/kW, respectively. The efficiency of the two make up air handlers is average when compared to the other tested facilities of various class ratings ranging from class 10 to 10,000. Make up air handler efficiencies at these tested facilities ranged from 537 to 1,797 cfm/kW.

Table 12. Cleanroom Metrics

Description		***MBE/Metal/ Junction Formation Cleanrooms***	***Hybridization/Micro-Optics/ONM Array Production Assembly/ Bonding Cleanrooms***
		Class 100	*Class 10,000*
MUAH Efficiency	cfm/kW	995	1,000
Make Up Air	cfm/sf	17.4	3.7
Make Up Fan Power Density [1]	W/sf	17.4	3.7
Recirculation Air Handler Efficiency	cfm/kW	1,655	1,756
Recirculation Air	cfm/sf	89.1	10.7
Recirculation Air Changes per Hour	ACH	594	72
Recirculation Fan Power Density [1]	W/sf	53.9	6.1
Lighting Power Density [2]	W/sf	1.2	1.6
Process Tools Power Density [2]	W/sf	5.9	1.8

1. *Calculated as total kW load divided by the primary area of the cleanroom.*
2. *Calculated as total kW load divided by the combined area of the cleanroom and the support room (secondary area) that contains the lighting and process tools.*

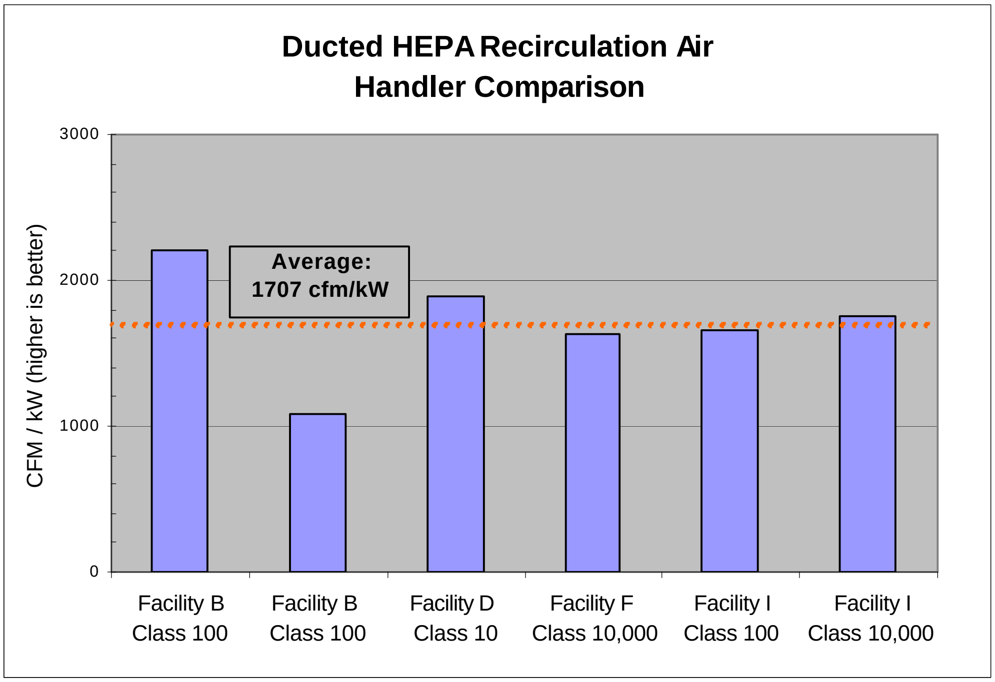


Figure 2. Ducted HEPA Recirculation Air Handler Efficiencies of Measured Facilities (Various Class Ratings)

Chilled Water Systems

Metrics of "kW/ton" are based on the total average equipment power and the average operating tonnage of the chilled water plant. These figures are useful for making comparisons between facilities, but more substantial information is expressed in the metric plots in Appendix B that reflect "kW/ton" performance at a sampling frequency of one minute over the course of a week. This type of information can be used to diagnose operational problems as well as evaluate the overall design performance.

Table 13. Chiller Efficiencies

Component	*Metric*
Chillers	0.96 kW/ton
Chilled Water Pumps	0.06 kW/ton
Chilled Water System	1.03 kW/ton
Cooling Load Density [1]	76.8 sf/ton
Process Cooling Chiller	1.52 kW/ton

1. *Cooling Load Density is the total conditioned area of the building served by the central plant, divided by the average plant tonnage.*

VI. SITE OBSERVATIONS REGARDING ENERGY EFFICIENCY

There are a number of potential areas for energy savings at Facility I. This section includes a general description of the most significant opportunities observed by the monitoring team.

Target the Humidity Control Sequences for Energy Reduction

During the measurement period it was observed that the air handling units were cycling frequently between humidification and dehumidification. This is a very inefficient mode of operation. During dehumidification, the air must be sub cooled, that is cooled below the sensible temperature at which it is to be delivered, resulting in the need for a reheat coil to raise the air to the supply temperature. The resulting energy use is two fold – extra energy is used to cool the air enough to dehumidify it, and then additional extra energy is used to increase the air after the dehumidification process is complete.

The majority of cleanroom spaces are controlled to much tighter humidity requirements (43% +/- 2%) than originally specified (up to 50% +/- 10%). The frequent, and energy intensive, cycling between dehumidification and humidification indicates the control loops would benefit from tuning to reduce the continuous oscillation. The control is made significantly more difficult by the current tight humidity control setpoints. Dehumidification requires that the air be "sub-cooled," meaning the air is cooled to a point that heating energy must be used to reheat it – a waste of both cooling and heating energy if the dehumidification is not actually required to meet the space conditions.

The chilled water humidity control setpoints should be modified to match the control ranges called out in the design documentation (drawing M5.8). Wider humidity control bands will significantly reduce the dehumidification and reheat energy requirements.

Optimize Chiller Operation with a Chilled Water Reset

Once dehumidification is brought under control, a chilled water reset can be implemented to decrease chiller energy use. The chiller will operate more efficiently when supplying a higher temperature chilled water. A higher temperature of chilled water, about 46°F rather than 42°F, should be capable of meeting the facility's load when the system is not dehumidifying. For internal load dominated plants such as this, it is recommended that the chilled water reset be based upon valve position rather than outdoor air temperature. This works by polling all the chilled water valves for there percent open value. If all the chilled water valves are less than 90% open, it is a direct indication that less cooling is required to meet the space loads. The chilled water supply temperature is then slowly increased until a least one valve is 90% open. When a valve position exceeds 90%, the chilled water temperature setpoint is reduced to meet the additional demand. Also, when dehumidification is called for the chilled water temperature must be set down to around 42°F to provide the subcooling required.

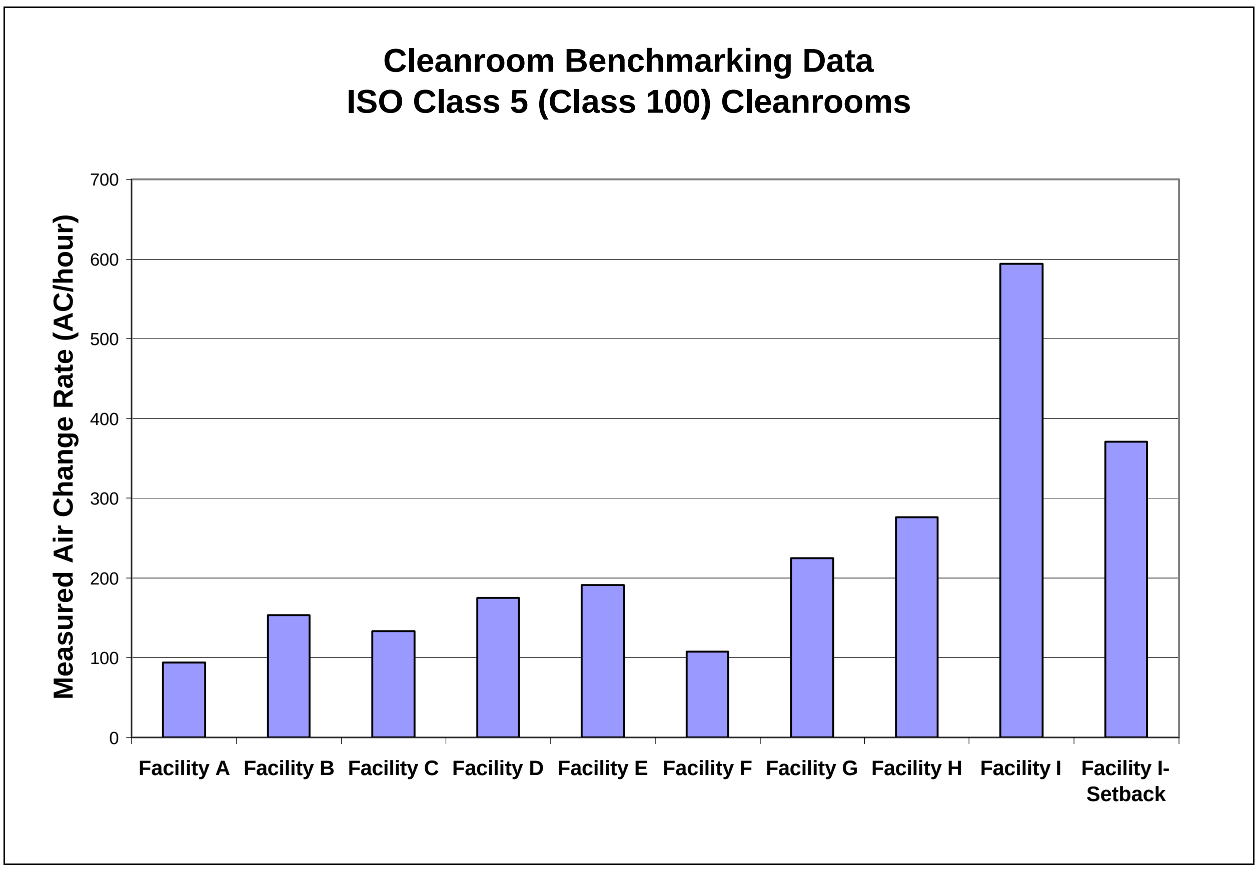
Implement Free Cooling for Process Chilled Water

Currently a 50 ton air-cooled chiller is used to supply a process chilled water loop. Due to the nature of the chiller and the low load on the chiller, the process chilled water chiller is operating at very poor efficiency – with the majority of operation in the range of 1.5 kW/ton to 2.5 kW/ton (Title 24 minimum performance is 1.25 kW/ton for an air cooled chiller and 0.8 kW/ton for a water cooled chiller).

The process chilled water supply is maintained at a temperature of about 63°F. This temperature could be easily supplied for a significant portion of the year via an evaporative cooling tower at an energy cost of less than 0.2 kW/ton. Make up water for the tower could be supplied for the evaporative cooling tower from the RO reject water stream, which would provide from 2,500 – 4000 gallons per day (dependent on RO water usage). Use of RO reject water for cooling tower makeup has been successfully adopted at other cleanroom sites in arid climates, such as Phoenix, AZ, and is highly recommended. Use of free cooling would save from 100,000kWh to 200,000 kWh per year.

Reduce Cleanroom Air Change Rate

The cleanroom design air change rates are relatively high for this class of cleanroom, in some cases over 500 ACH for class 100 space. While the air change rate is high within the set of Class 100 facilities benchmarked, it does fall within the range recommended by other sources (see http://cr.pennnet.com/Articles/Article_Display.cfm?Section=Archives&Subsection=Display&ARTICLE_ID=165797 or Appendix for a copy of CleanRooms Magazine article discussing this issue). The benchmarking project has found that significantly lower air change rates are commonly used to provide the same class cleanroom environment, and with the good gowning protocol observe it is expected that a lower rate could be used without problem. This has been recognized by site personnel who have already reduced the air change rates somewhat. A reduction to a level of 250 - 300 ACH should be investigated to further reduce energy usage. The setback is currently operating at an air change rate equivalent to the normal air change rate of many operation Class 100 cleanrooms; it too offers an opportunity for reduction.



Unoccupied Recirculation Flow Setback

The current recirculation air handler control is very energy efficient, with nighttime recirculation volumes being reduced. For RAH-4, A reduction in fan speed of about 30% at night, when the space is unoccupied, yields a measured power consumption reduction of 72% – recirculation air handler power drops from 64 kW to less than 18 kW. When all the recirculation units are considered, this is obviously a significant savings. The magnitude of savings is indicative of the power reductions that occur from small reductions in the airflow volume. Implementing a more active and aggressive control scheme for the fan power setback would increase the power savings further.

One active control methodology is to install occupancy sensor based lighting controls in the cleanroom space. By means of current transducers, monitor the lighting circuits to detect when the cleanroom lights are off. Since the cleanroom spaces have little to no natural lighting, the controls can assume that when the lights are off the space is unoccupied and recirculation rates can be reduced. As demonstrated by the current setback operation, a small setback is all that is required to achieve a large energy savings. A setback of 30% achieves the majority of energy savings and presents little threat of space hygiene problems even if the system is setback during an occupied period inadvertently.

Appendix A

Data Reports

Site Data

Customer Name: ***Facility I***

Site Name: ***Building I***

Customer

Address:	anon.	Contact:	anon.
City:	anon.	Contact Phone:	anon.
Zip:	anon.	First Contact:	anon.

Site

Address:	anon.	Contact:	anon.
City:	anon.	Contact Phone:	anon.
Service Territory	SCE		

Total Facility Area	69310 sf	Year Built:	2002
		Annual Hours Use:	8760
Total Cleanroom Area (Class 3 thru 8 only):	15430 sf	Customer Owned	☐
Class 3 - 4 (1 - 10) Area	-99 sf	Corporate Payback	-77
Class 5 (100) Area:	11120 sf	Self Evaluation	-77
Class 6 (1000) Area:	-99 sf	Industry Type:	Other
Class 7 (10,000) Area	4310 sf		
Class 8 (100,000) Area	-77 sf		
Mini-environment Area	-77 sf		
Support Clean Area	-77 sf		
Support NonClean Area	-77 sf		
Sub Cleanroom Area	-77 sf		

Utility Billing

Annual Electric Use:	8260000	kWh/yr
Annual Electic Cost:	999900	$/yr
Average Electric Rate	0.121	$/kWh
Annual Fuel Use:	11900	Therms/yr
Annual Fuel Cost:	77000	$/yr
Peak Power:	1706	kW
Avg Power Factor	-77	

Billing Notes

Cleanroom Data

Customer Name: ***Facility I***
Site Name: ***Building I***
Cleanroom Name: ***MBE/Metal/Junction Formation - Class 100***

Class: Class 100
ISO Class: ISO Class 5
Fan System Type Recirculation AHU

HEPA Filter Coverage 100 %
Filter Effective Area 85 %
Ceiling Filter Efficiency -77

Annual Hours Use: 8760
Heat Recovery ☐
Raised Floor: ☑
Exhaust Fan(s): ☑

Building Area: 69,310 sf
Primary Cleanroom Area 2,305 sf
Secondary Cleanroom Area 1,355 sf

Primary Cleanroom Ceiling Heigh 9 ft
Secondary Cleanroom Ceiling Heigh -77 ft

Power

Monitoring Start Date: 3/15/2004
Monitoring End Date: 3/23/2004

	Design			Measured				
	Unit	Value	Source	Value	Max	Min	Source	Accuracy (+/-)
Lighting:	kW	-77		4.2	-77	-77	Rumsey Eng	5%
Process:	kW	-77		20.3	-77	-77	Rumsey Eng	5%
Other:	kW	-77		-77	-77	-77		

Space Conditions

	Design				Measured				
	Unit	Value	+/-	Source	Value	Max	Min	Source	Accuracy (+/-)
Temperature:	F	69	2	Submittals	66.8	67.7	65.9	Rumsey Eng	5%
Humidity:	%RH	45	10	Submittals	47.6	51.2	43.9	Rumsey Eng	10%
Ceiling Velocity	fpm	-77	-77		105	-77	-77	Calculation	20%
Pressurization:	in wg	-77	-77		0.14	-77	-77	Rumsey Eng	10%

Cleanroom Description

This cleanroom is served by one makeup air handler and two recirculation air handlers.

MUAH Data

Customer Name: ***Facility I***
Site Name: ***Building I***
Cleanroom Name: ***MBE/Metal/Junction Formation - Class 100***

MUAH Name: ***AHU-2***

Number of Units: 1

	Design			Measured				
	Unit	Value	Source	Average	Max	Min	Source	Accuracy (+/-)
Air Flow:	cfm	40000	Drawings	995			Calculation	20%
MUAH Fan Power:	kW	-77		40.2			Rumsey Eng	5%
Efficiency:	cfm/kW	-99		25				
Total Air Flow:	cfm	40000	Drawings	995				
Total Power:	kW	-99.0		40.2				
VFD Speed:	Hz	-77		60			Rumsey Eng	5%
Supply Air Temperature	°F	-77		-77	-77	-77		
Supply Setpoint	°F	47	Drawings	-77				
Supply RH:	%	-77		-77	-77	-77		
RH Setpoint:	%	-77		-77				
Fan Pressure Rise:	in	-77		-77				
Filter Pressure Drop:	in	-77		-77				
Sensible Cooling Load	tons	-77		-77	-77	-77		
Coil Face Velocity	fpm	-77		-77				

MUAH Description

Fan running at full speed due to burned out variable frequency drive.

RCU Data

Customer Name: ***Facility I***

Site Name: ***Building I***

Cleanroom Name: ***MBE/Metal/Junction Formation - Class 100***

RCU Name: ***RAH-3 & RAH-4***

Number of Units: 2

Design / Measured

	Design Unit	Design Value	Design Source	Measured Average	Measured Max	Measured Min	Measured Source	Accuracy (+/-)
Air Flow:	cfm	26000	Drawings	205330			Balance Report	20%
RCU Fan Power:	kW	-77		124.1			Rumsey Eng	5%
Efficiency:	cfm/kW	-99		1655				
VFD Speed:	Hz	-77		48			Rumsey Eng	5%
Supply Air Temperature	°F	-77		66	68	61	Rumsey Eng	5%
Return Air Temperature	°F	-77		67	70	65	Rumsey Eng	2%
Supply Setpoint	°F	-77		-77				
RH Setpoint:	%	-77		43			EMS/BMS	
Supply RH:	%	-77		-77	-77	-77		
Fan Pressure Rise:	in w.g.	-77		2.2			Rumsey Eng	10%
Filter Pressure Drop:	in w.g.	-77		0.7			Rumsey Eng	10%
Sensible Cooling Load	tons	-77		-77				
Coil Face Velocity	fpm	-77		-77				

RCU Description

Exhaust Data

Customer Name: ***Facility I***
Site Name: ***Building I***
Cleanroom Name: ***MBE/Metal/Junction Formation - Class 100***

Exhaust Name: ***EF-8A & 8B***

Number of Units: 2

	Design				Measured		
	Unit	**Value**	**Source**		**Average**	**Source**	**Accuracy (+/-)**
Exhaust Flow:	cfm	20700	Drawings		20700	Calculation	20%
Fan Power:	kW	-77			11.6	Rumsey Eng	5%
Efficiency:	cfm/kW	-99			1784		
Total Exhaust Flow	cfm	41400			41400		
Total Power:	kW	-99.0			23.2		
Fan Pressure Rise:	in	3	Drawings		-77		0%

Exhaust Description

Exhaust Data

Customer Name: ***Facility I***
Site Name: ***Building I***
Cleanroom Name: ***MBE/Metal/Junction Formation - Class 100***

Exhaust Name: ***EF-13***

Number of Units: 1

	Design			Measured		
	Unit	Value	Source	Average	Source	Accuracy (+/-)
Exhaust Flow:	cfm	3500	Drawings	3500	Calculation	20%
Fan Power:	kW	-77		1.8	Rumsey Eng	5%
Efficiency:	cfm/kW	-99		1944		
Total Exhaust Flow	cfm	3500		3500		
Total Power:	kW	-99.0		1.8		
Fan Pressure Rise:	in	3	Drawings	-77		0%

Exhaust Description

Exhaust Data

Customer Name: ***Facility I***

Site Name: ***Building I***

Cleanroom Name: ***MBE/Metal/Junction Formation - Class 100***

Exhaust Name: ***EF-15***

Number of Units: 1

	Design				Measured		
	Unit	Value	Source		Average	Source	Accuracy (+/-)
Exhaust Flow:	cfm	600	Drawings		600	Calculation	20%
Fan Power:	kW	-77			0.38	Rumsey Eng	5%
Efficiency:	cfm/kW	-99			1579		
Total Exhaust Flow	cfm	600			600		
Total Power:	kW	-99.0			0.4		
Fan Pressure Rise:	in	0.5	Drawings		-77		0%

Exhaust Description

Cleanroom Data

Customer Name: ***Facility I***
Site Name: ***Building I***
Cleanroom Name: ***Hybridization/Micro-Optics/ONM/Bonding - Cls 10K***

Class: Class 10,000
ISO Class: ISO Class 7
Fan System Type Recirculation AHU

HEPA Filter Coverage 14 %
Filter Effective Area 85 %
Ceiling Filter Efficiency -77

Annual Hours Use: 8760
Heat Recovery ☐
Raised Floor: ☐
Exhaust Fan(s): ☐

Building Area: 69,310 sf
Primary Cleanroom Area 3,750 sf
Secondary Cleanroom Area 560 sf

Primary Cleanroom Ceiling Height 9 ft
Secondary Cleanroom Ceiling Height -77 ft

Power

Monitoring Start Date: 3/15/2004
Monitoring End Date: 3/23/2004

Design

	Unit	Value	Source
Lighting:	kW	-77	
Process:	kW	-77	
Other:	kW	-77	

Measured

Value	Max	Min	Source	Accuracy (+/-)
6.1	-77	-77	Rumsey Eng	5%
6.9	-77	-77	Rumsey Eng	5%
-77	-77	-77		

Space Conditions

Design

	Unit	Value	+/-	Source
Temperature:	F	69	2	Submittals
Humidity:	%RH	45	15	Submittals
Ceiling Velocity	fpm	-77	-77	
Pressurization:	in wg	-77	-77	

Measured

Value	Max	Min	Source	Accuracy (+/-)
65.8	68.1	64	Rumsey Eng	5%
50.8	58.6	44.4	Rumsey Eng	10%
90	-77	-77	Calculation	20%
0.1	-77	-77	Rumsey Eng	20%

Cleanroom Description

This cleanroom is served by one makeup air handler and one recirculation air handler.

MUAH Data

Customer Name: ***Facility I***
Site Name: ***Building I***
Cleanroom Name: ***Hybridization/Micro-Optics/ONM/Bonding - Cls 10K***

MUAH Name: ***AHU-3***

Number of Units: 1

	Design			Measured				
	Unit	**Value**	**Source**	**Average**	**Max**	**Min**	**Source**	**Accuracy (+/-)**
Air Flow:	cfm	15000	Drawings	1000			Calculation	20%
MUAH Fan Power:	kW	-77		13.7			Rumsey Eng	5%
Efficiency:	cfm/kW	-99		73				
Total Air Flow:	cfm	15000	Drawings	1000				
Total Power:	kW	-99.0		13.7				
VFD Speed:	Hz	-77		55			Rumsey Eng	5%
Supply Air Temperature	°F	-77		-77	-77	-77		
Supply Setpoint	°F	47	Drawings	-77				
Supply RH:	%	-77		-77	-77	-77		
RH Setpoint:	%	-77		-77				
Fan Pressure Rise:	in	-77		-77				
Filter Pressure Drop:	in	-77		-77				
Sensible Cooling Load	tons	-77		-77	-77	-77		
Coil Face Velocity	fpm	-77		-77				

MUAH Description

RCU Data

Customer Name: ***Facility I***
Site Name: ***Building I***
Cleanroom Name: ***Hybridization/Micro-Optics/ONM/Bonding - Cls 10K***

RCU Name: ***RAH-6***

Number of Units: 1

Design / Measured

	Unit	Value	Source	Average	Max	Min	Source	Accuracy (+/-)
Air Flow:	cfm	65000	Drawings	40260			Balance Report	20%
RCU Fan Power:	kW	-77		22.9			Rumsey Eng	5%
Efficiency:	cfm/kW	-99		1758				
VFD Speed:	Hz	-77		42			Rumsey Eng	5%
Supply Air Temperature	°F	-77		66	69	62	Rumsey Eng	5%
Return Air Temperature	°F	-77		67	69	65	Rumsey Eng	5%
Supply Setpoint	°F	-77		-77				
RH Setpoint:	%	-77		-77				
Supply RH:	%	-77		-77	-77	-77		
Fan Pressure Rise:	in w.g.	-77		1.8			Rumsey Eng	10%
Filter Pressure Drop:	in w.g.	-77		0.4			Rumsey Eng	10%
Sensible Cooling Load	tons	-77		-77				
Coil Face Velocity	fpm	-77		-77				

RCU Description

Exhaust Data

Customer Name: ***Facility I***
Site Name: ***Building I***
Cleanroom Name: ***Hybridization/Micro-Optics/ONM/Bonding - Cls 10K***

Exhaust Name: ***EF-18***

Number of Units: 1

	Design			Measured		
	Unit	Value	Source	Average	Source	Accuracy (+/-)
Exhaust Flow:	cfm	800	Drawings	800	Calculation	20%
Fan Power:	kW	-77		0.47	Rumsey Eng	5%
Efficiency:	cfm/kW	-99		1702		
Total Exhaust Flow	cfm	800		800		
Total Power:	kW	-99.0		0.5		
Fan Pressure Rise:	in	0.5	Drawings	-77		0%

Exhaust Description

Chiller Data

Customer Name: ***Facility I***
Site Name: ***Building I***

Chiller Name: ***Chilled Water Plant***

End Use:	Combined			
Nominal Tons:	170			
Total Number of Chillers of this type, including Standb	3		Monitoring Start Date:	3/18/2004
Number of Standby Chillers of this type	1		Monitoring End Date:	3/23/2004

Design / Measured

	Unit	Value	Source	Average	Max	Min	Source	Accuracy (+/-)
Total Power:	kW	-77		195.5	358.8	93.2	Rumsey Eng	0.05
Cooling Supplied	Tons	340	Drawings	201	328	108	Calculation	0.2
Efficiency:	kW/Ton	-99.00		0.97				

Chiller Description

Chillers 1 and 3 were running during monitoring period.

Chiller Name: ***Process Chiller***

End Use:	Process			
Nominal Tons:	50			
Total Number of Chillers of this type, including Standb	1		Monitoring Start Date:	3/18/2004
Number of Standby Chillers of this type	0		Monitoring End Date:	3/20/2004

Design / Measured

	Unit	Value	Source	Average	Max	Min	Source	Accuracy (+/-)
Total Power:	kW	-77		21.8	28.8	14.2	Rumsey Eng	0.05
Cooling Supplied	Tons	50	Drawings	17.8	48.4	4.4	Calculation	0.2
Efficiency:	kW/Ton	-99.00		1.22				

Chiller Description

Chilled Water Pump Loop Data

Customer Name: ***Facility I***
Site Name: ***Building I***

Pump Loop Name: **CHW Pumps**
Pump Loop Type: **Primary Chilled Water**

Number of Pumps: 3
Number Used as Backup 1

Monitoring Start Date 3/15/2004
Monitoring End Date 3/23/2004

Design / Measured

	Design			Measured				
	Unit	**Value**	**Source**	**Average**	**Max**	**MIn**	**Source**	**Accuracy (+/-)**
Supply Temp:	°F	40	Drawings	40.8	43.8	38.3	Rumsey Eng	2%
Return Temp:	°F	55	Drawings	48.4	54.2	43.3	Rumsey Eng	2%
Total Flow:	gpm	-77		641	759	435	Rumsey Eng	20%
Cooling Tons:	Tons	-99		203				
Total Power:	kW	-77		12.4	17.5	8.2	Rumsey Eng	5%
Efficiency:	kW/Ton	-99.000		0.061				
Head:	ft	65	Drawings	56.9	-77	-77	Rumsey Eng	5%

Chilled Water Pump Loop Description

Chilled water (CHW) pumps 1 and 3 were running during monitoring period.

Chilled Water Pump Loop Data

Customer Name: ***Facility I***

Site Name: ***Building I***

Pump Loop Name: **PCHW Pumps**

Pump Loop Type: **Process Chilled Water**

Number of Pumps: 2
Number Used as Backup 1

Monitoring Start Date 3/18/2004
Monitoring End Date 3/20/2004

Design / Measured

	Unit	Value	Source	Average	Max	MIn	Source	Accuracy (+/-)
Supply Temp:	°F	65	Drawings	62.9	64.9	60.6	Rumsey Eng	2%
Return Temp:	°F	75	Drawings	66.6	70.6	63.9	Rumsey Eng	2%
Total Flow:	gpm	120	Drawings	123	140	107	Rumsey Eng	20%
Cooling Tons:	Tons	50		19				
Total Power:	kW	-77		7.8	8.5	7.4	Rumsey Eng	2%
Efficiency:	kW/Ton	-99.000		0.411				
Head:	ft	95	Drawings	90	-77	-77	Rumsey Eng	5%

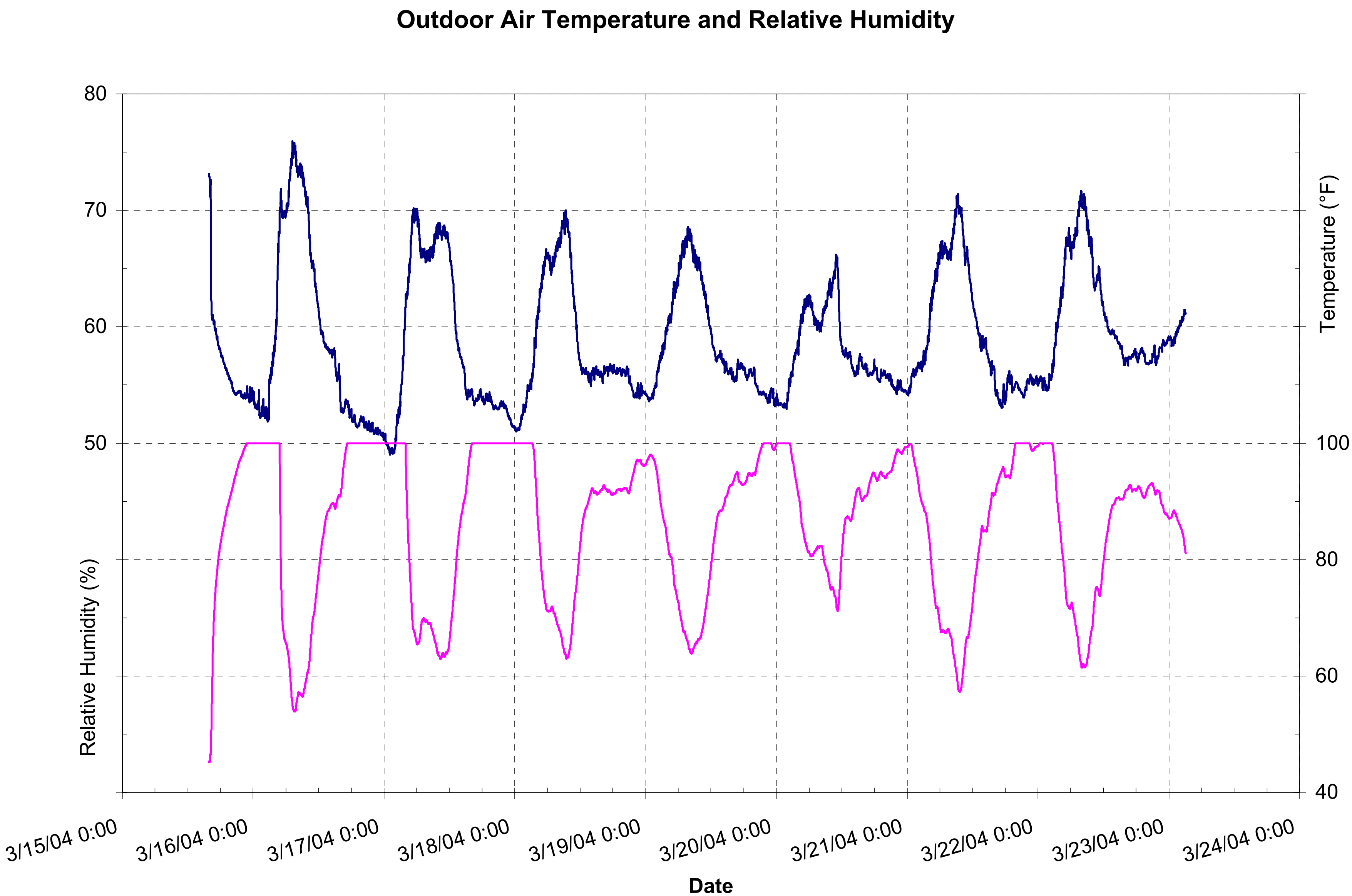
Chilled Water Pump Loop Description

PCHW pump 2 was running during monitoring period.

Appendix B

Trended Data Graphs

Outside Air Conditions

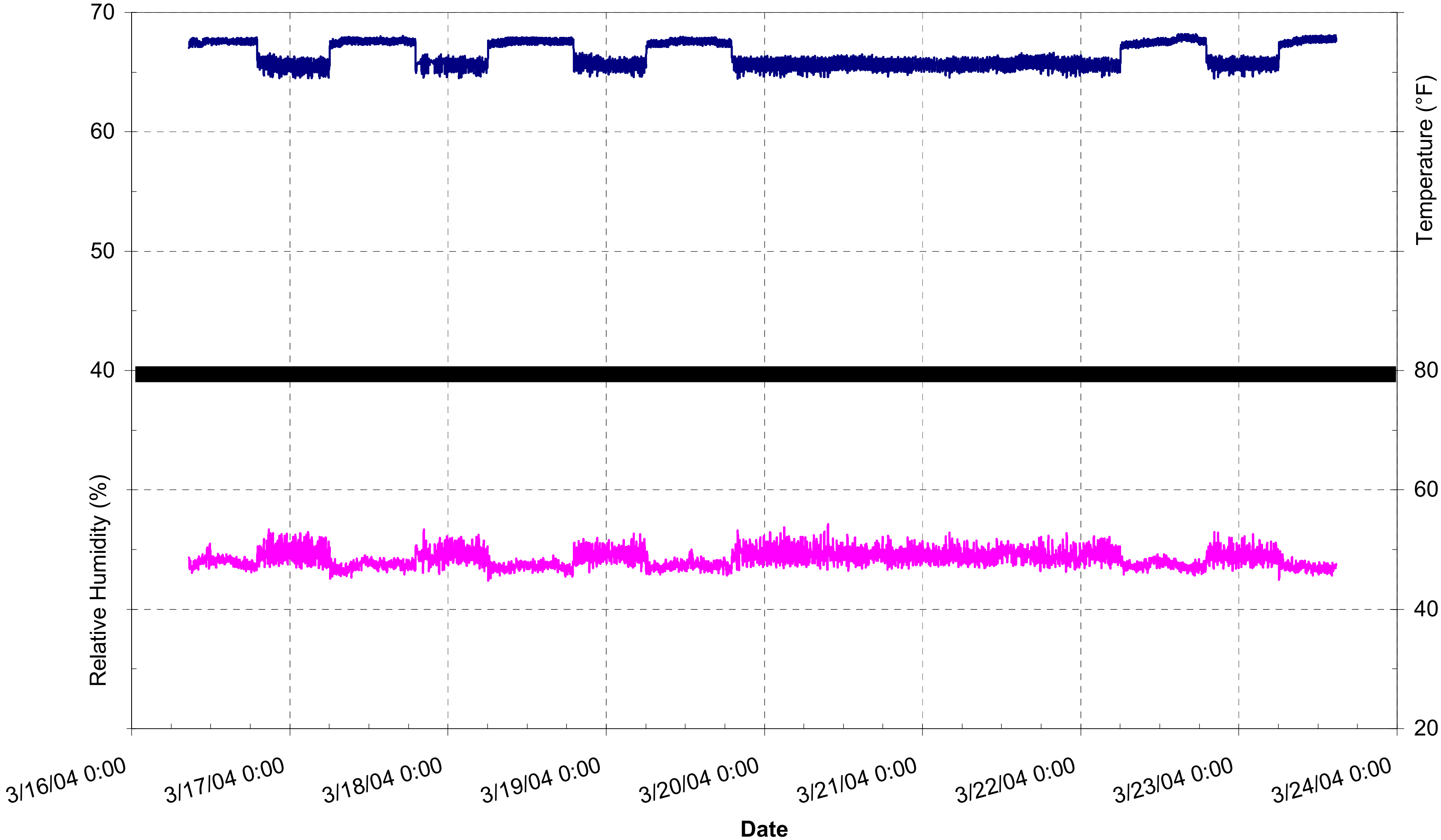


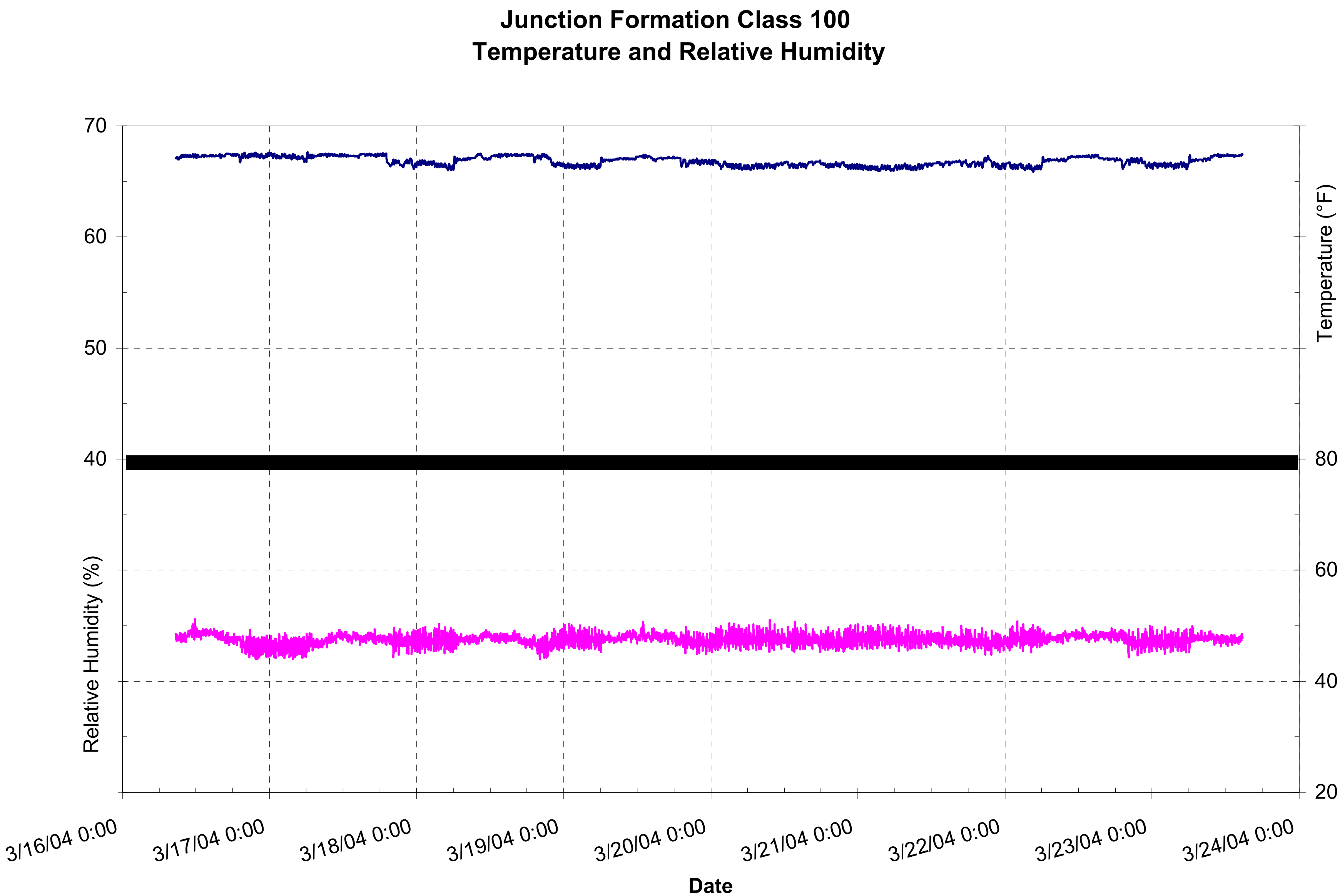
Outdoor Air Temperature and Relative Humidity
80
70
60
50
Relative Humidity (%)
Temperature (°F)
100
80
60
40
3/15/04 0:00
3/16/04 0:00
3/17/04 0:00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
3/24/04 0:00
Date

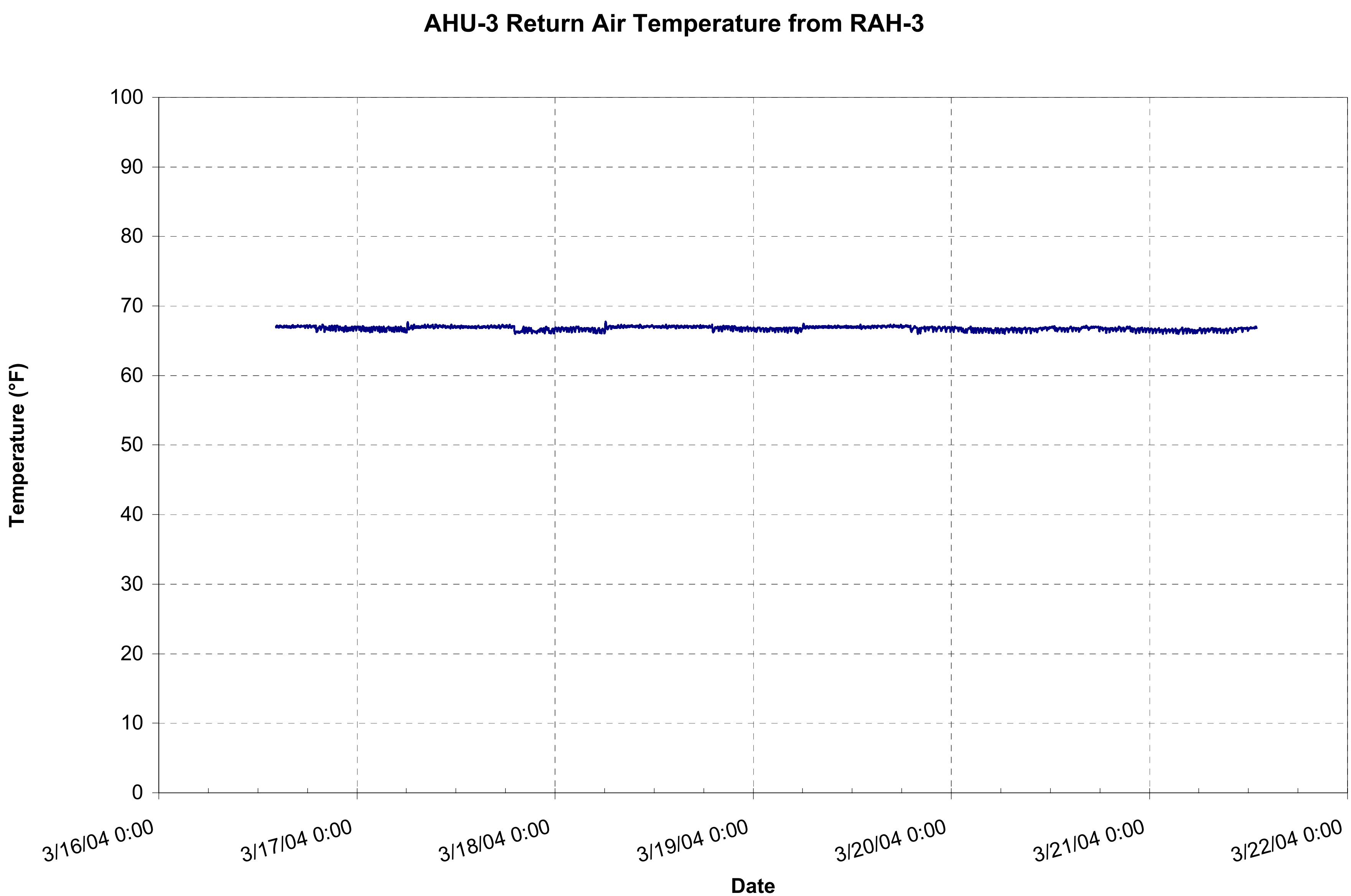
MBE/Metal/Junction Formation Cleanrooms

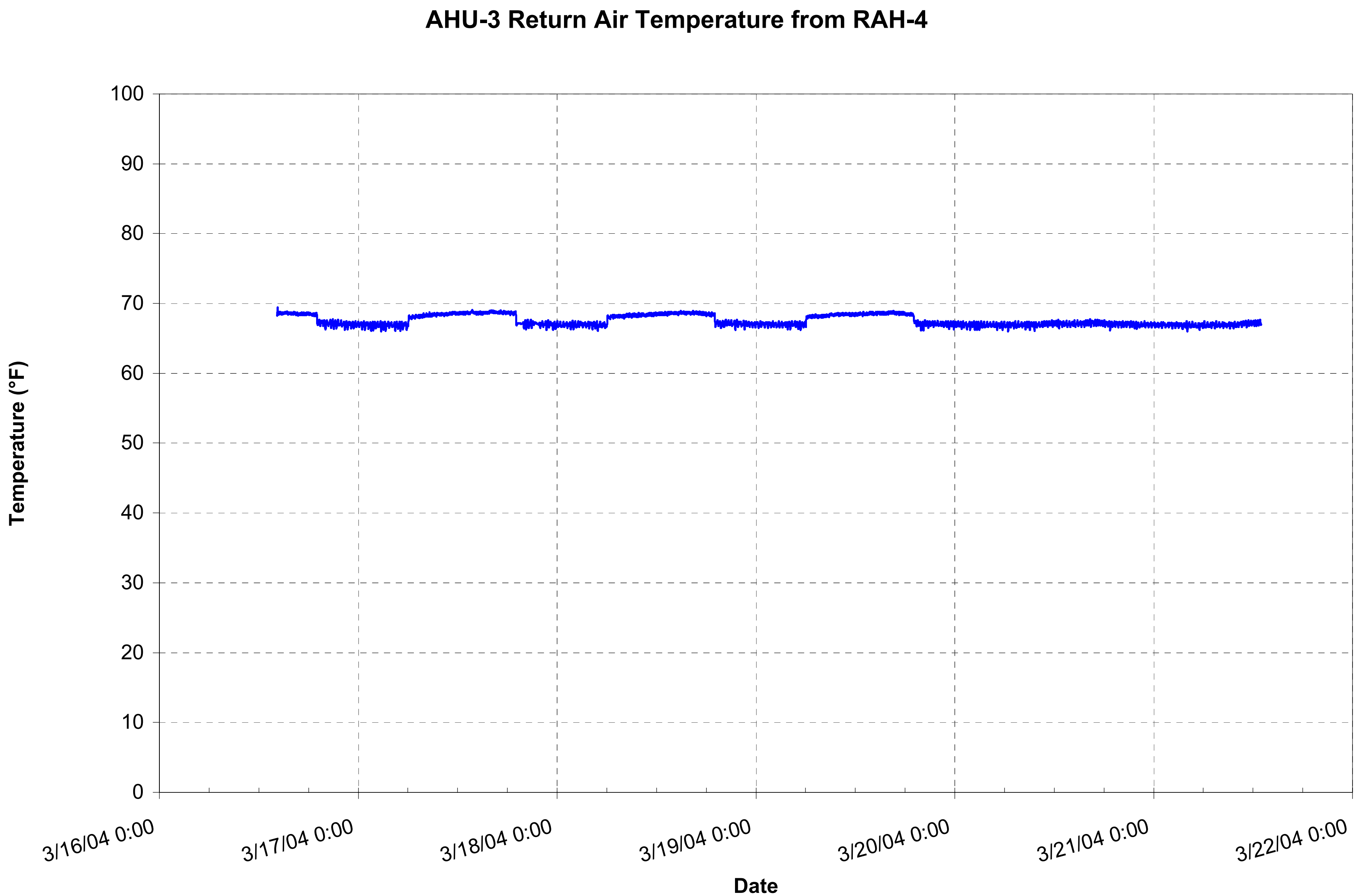
Class 100

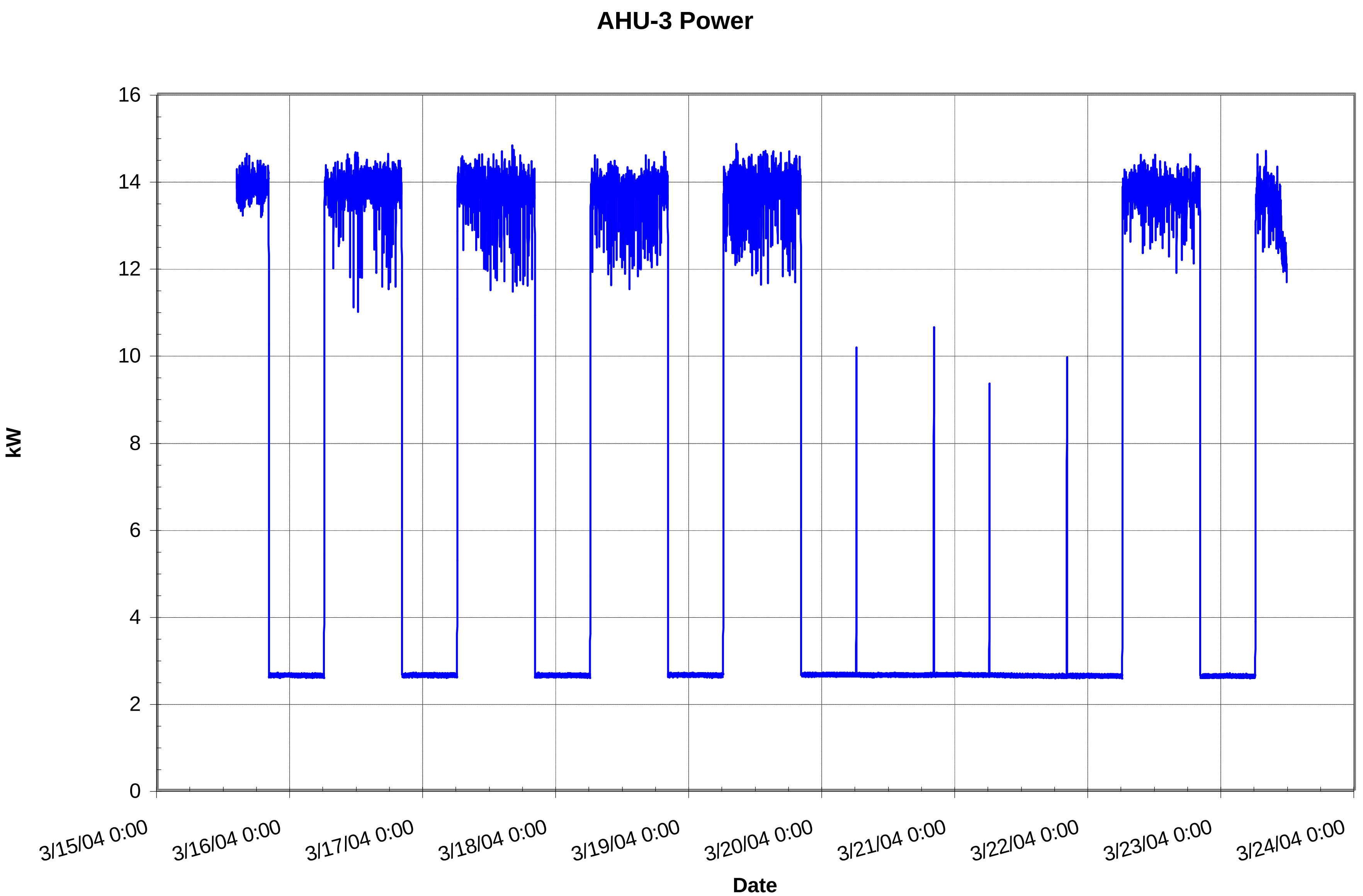
MBE Class 100
Temperature and Relative Humidity



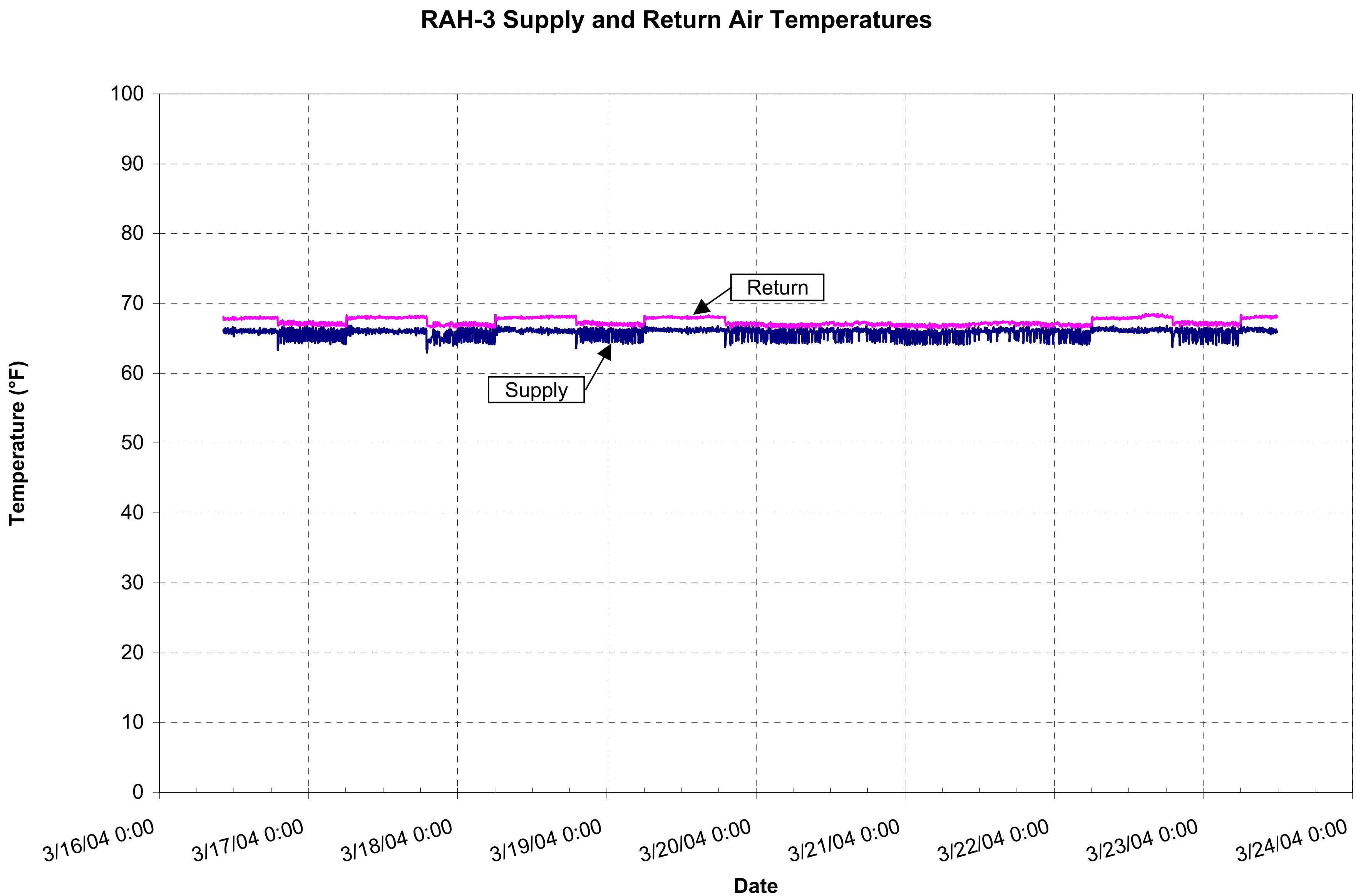

Junction Formation Class 100
Temperature and Relative Humidity
70
60
50
40
80
60
40
20
Temperature (°F)
Relative Humidity (%)
3/16/04 0:00
3/17/04 0:00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
3/24/04 0:00
Date


AHU-3 Return Air Temperature from RAH-3
Temperature (°F)
100
90
80
70
60
50
40
30
20
10
0
3/16/04 0:00
3/17/04 0:00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
Date

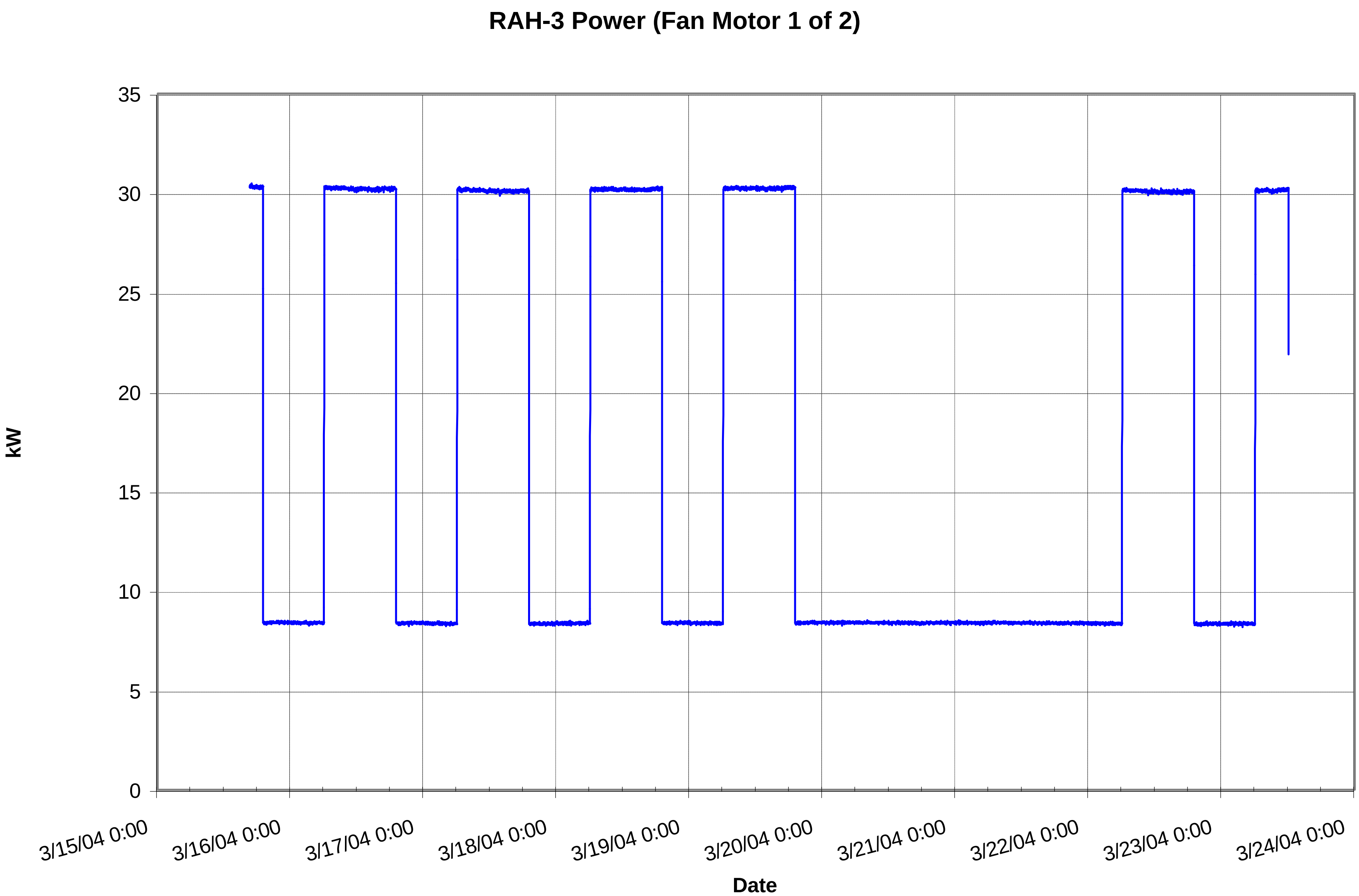

AHU-3 Return Air Temperature from RAH-4
Temperature (°F)
100
90
80
70
60
50
40
30
20
10
0
3/16/04 0:00
3/17/04 0:00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
Date

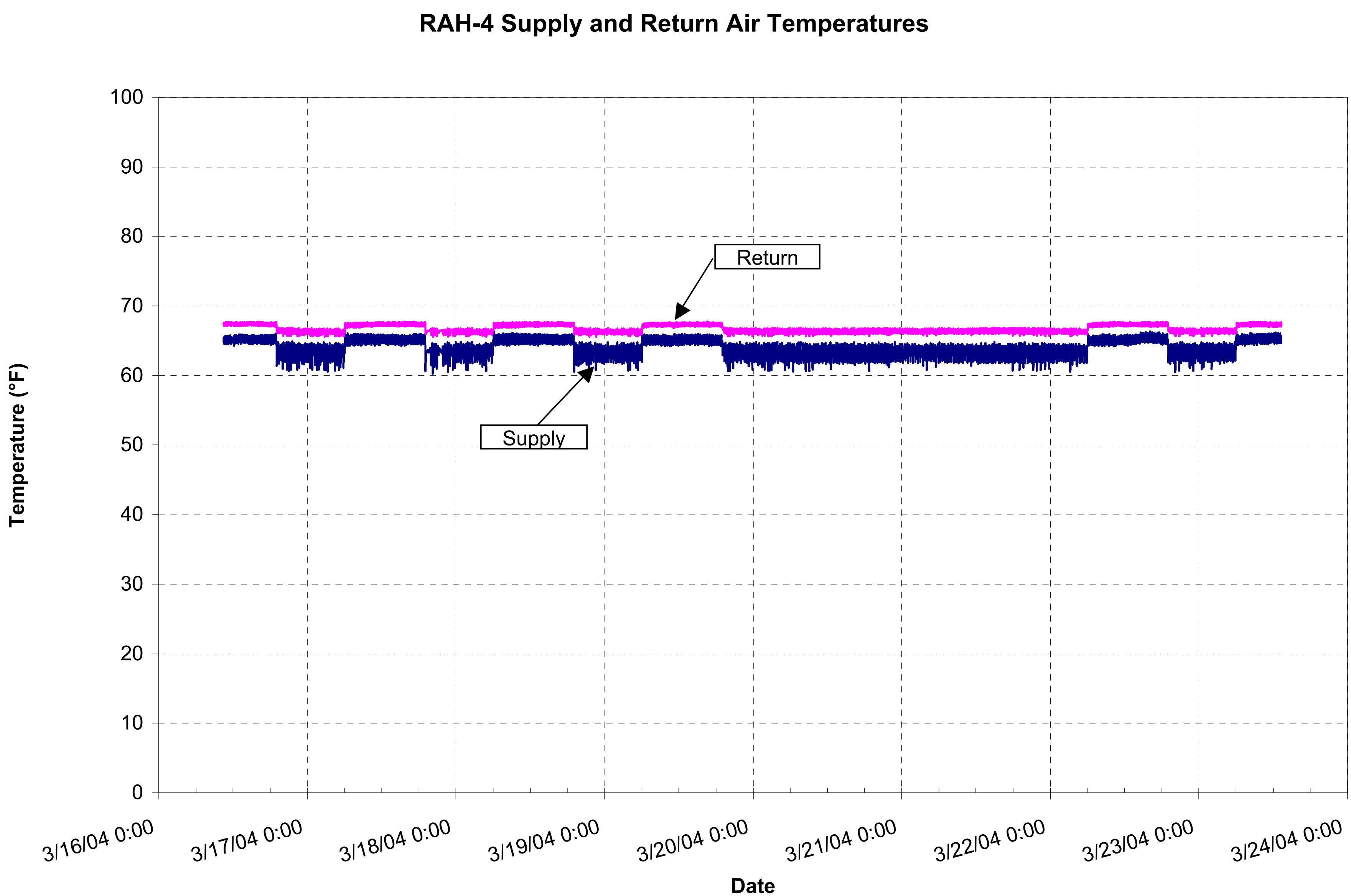


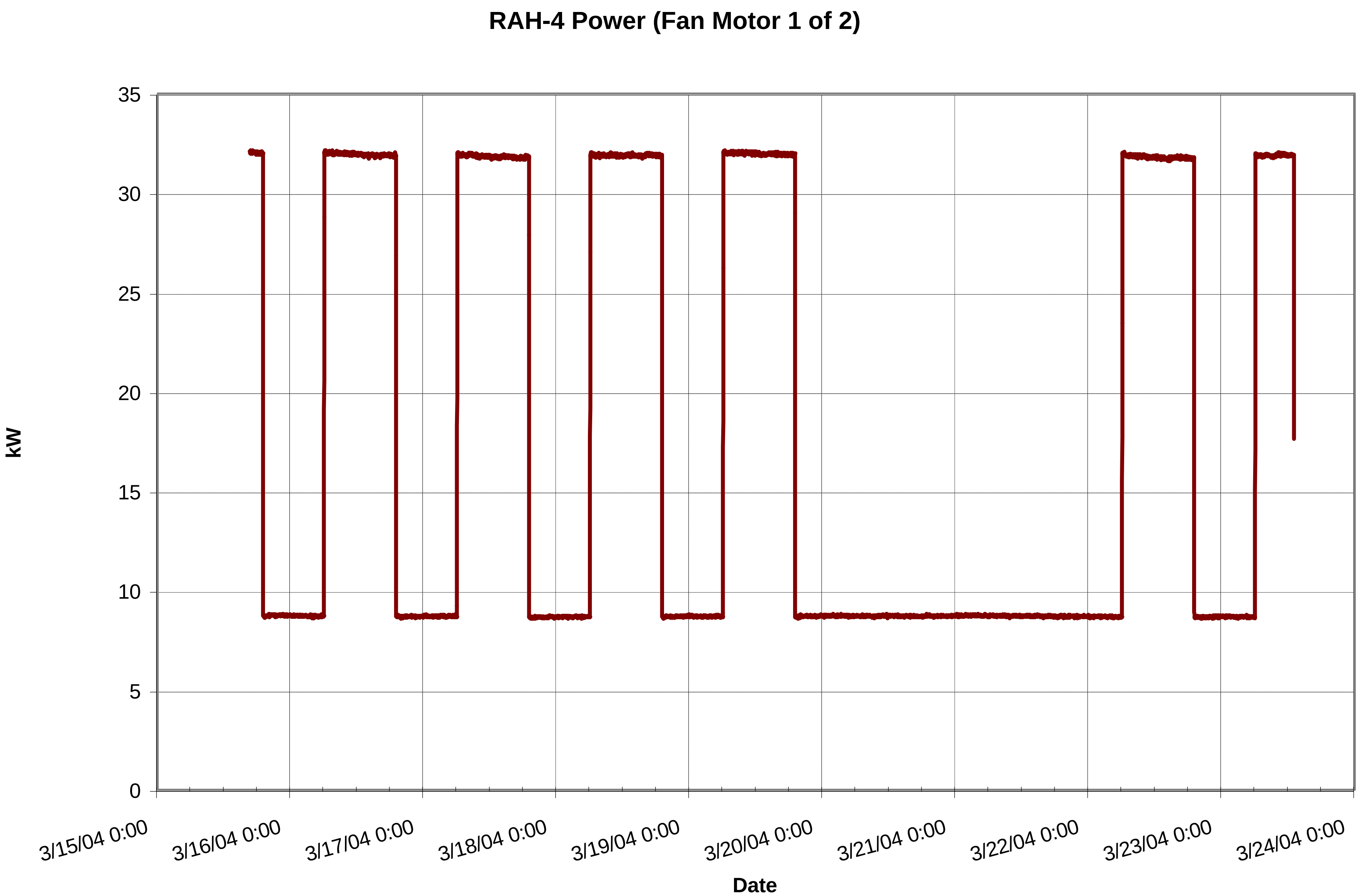
AHU-3 Power
kW
16
14
12
10
8
6
4
2
0
3/15/04 0:00
3/16/04 0:00
3/17/04 0:00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
3/24/04 0:00
Date



RAH-3 Supply and Return Air Temperatures
Temperature (°F)
100
90
80
70
60
50
40
30
20
10
0
Return
Supply
3/16/04 0:00
3/17/04 0:00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
3/24/04 0:00
Date


RAH-3 Power (Fan Motor 1 of 2)
kW
35
30
25
20
15
10
5
0
3/15/04 0:00
3/16/04 0:00
3/17/04 0:00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
3/24/04 0:00
Date


RAH-4 Supply and Return Air Temperatures
Temperature (°F)
100
90
80
70
60
50
40
30
20
10
0
Return
Supply
3/16/04 0:00
3/17/04 0:00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
3/24/04 0:00
Date

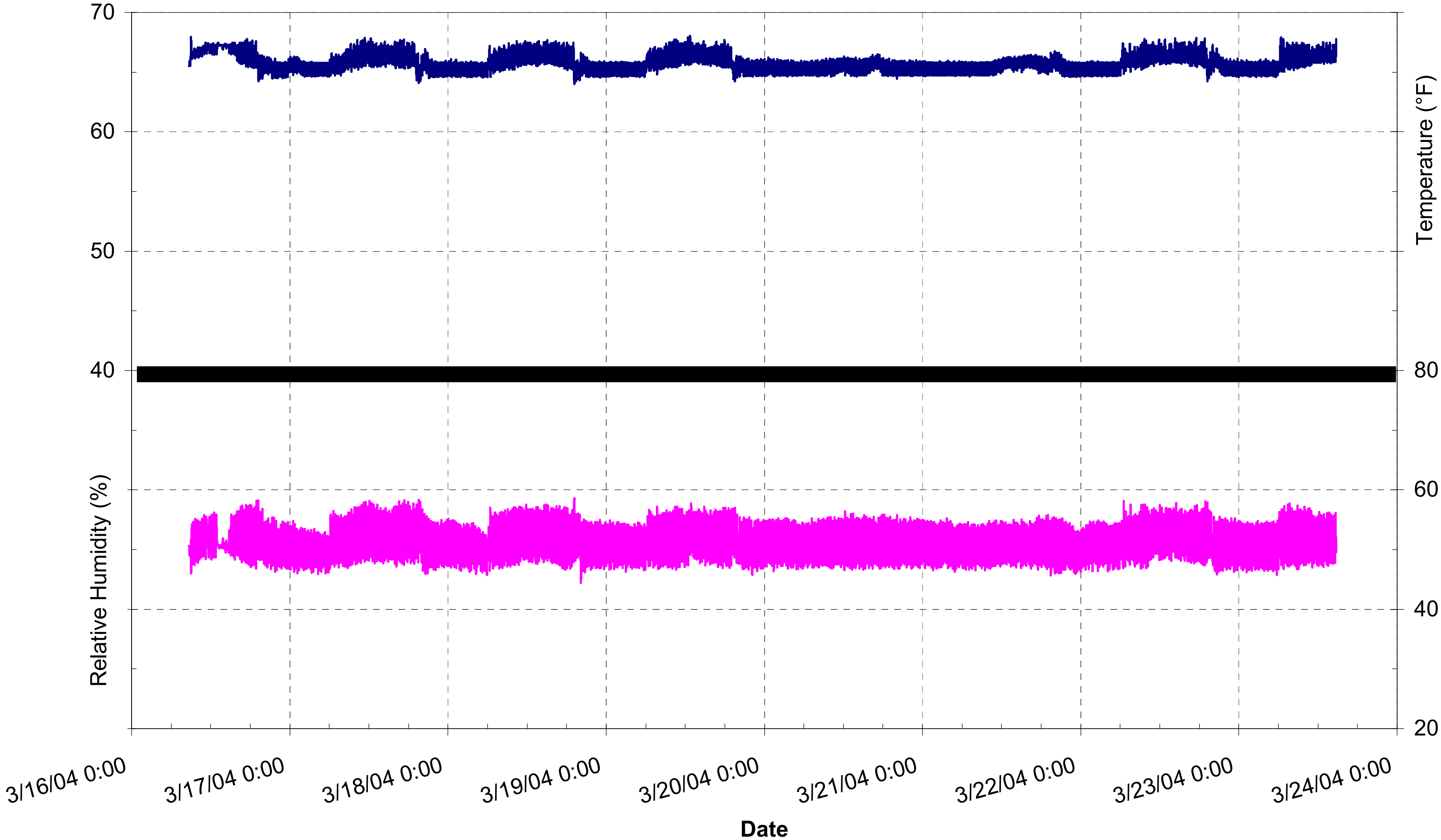


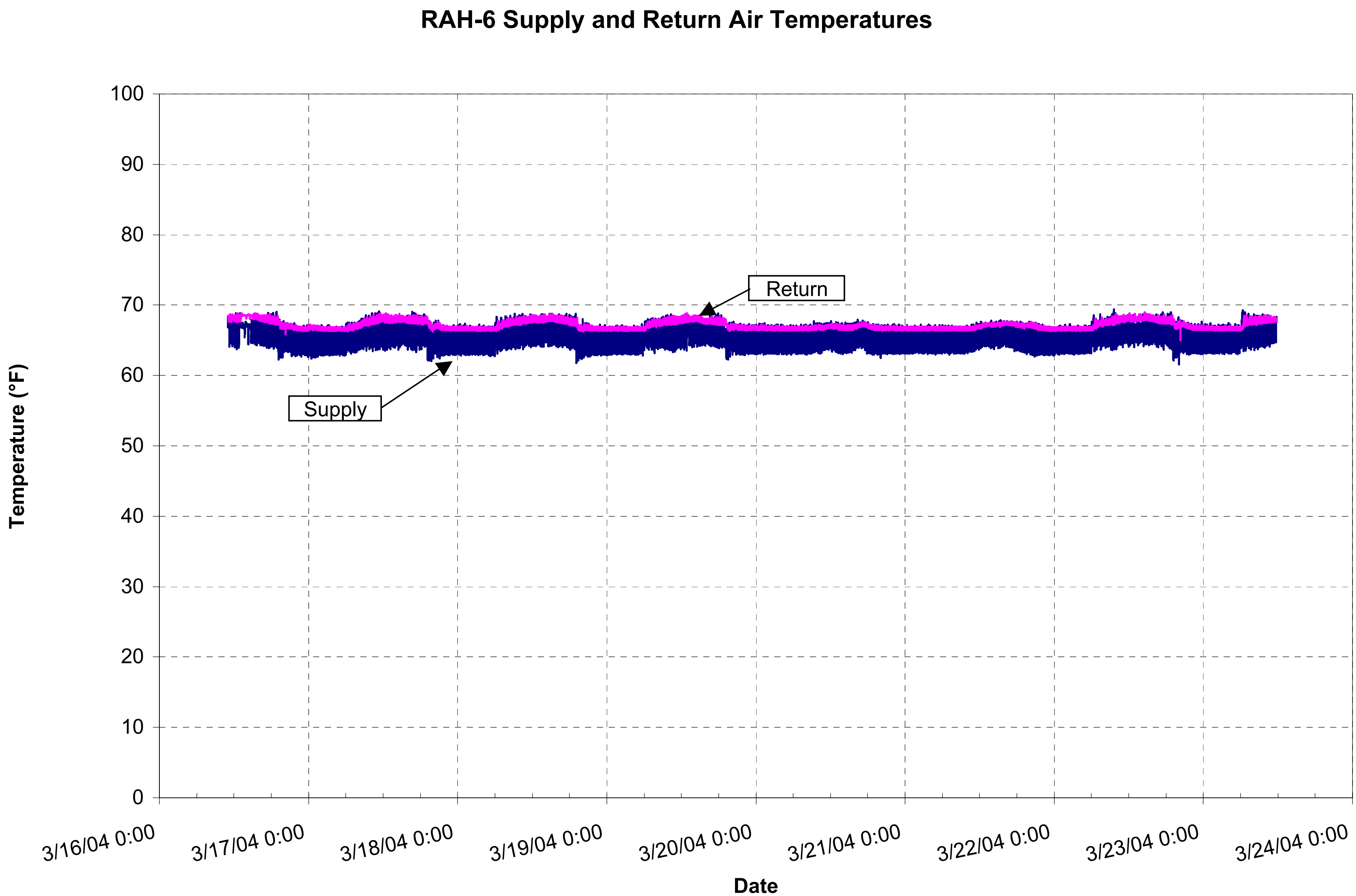
RAH-4 Power (Fan Motor 1 of 2)
kW
35
30
25
20
15
10
5
0
3/15/04 0:00
3/16/04 0:00
3/17/04 0:00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
3/24/04 0:00
Date

Hybridization/Micro-Optics/ ONM Array Production Assembly/Bonding Cleanrooms

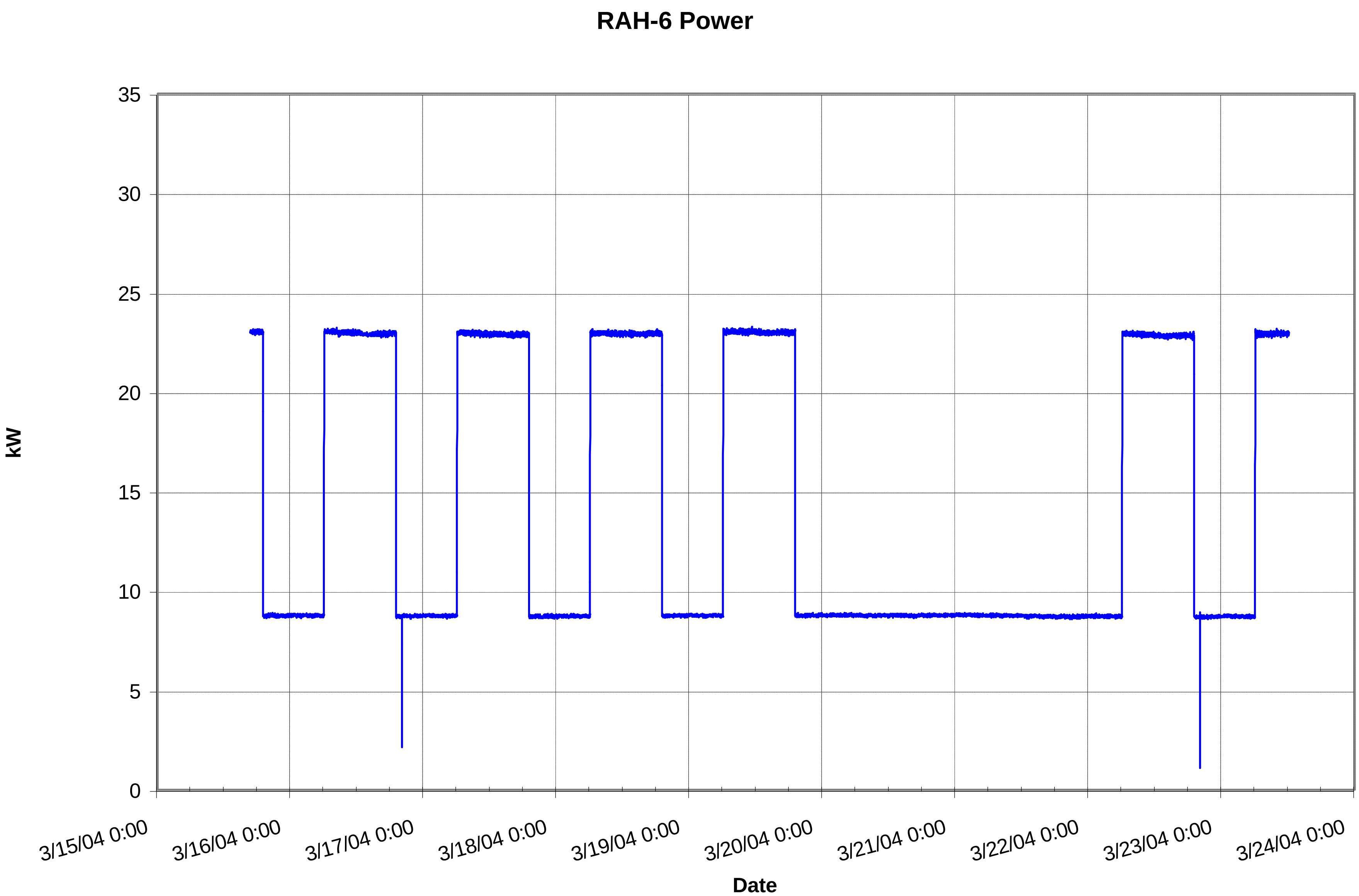
Class 10,000

Hybridlization Class 10,000
Temperature and Relative Humidity



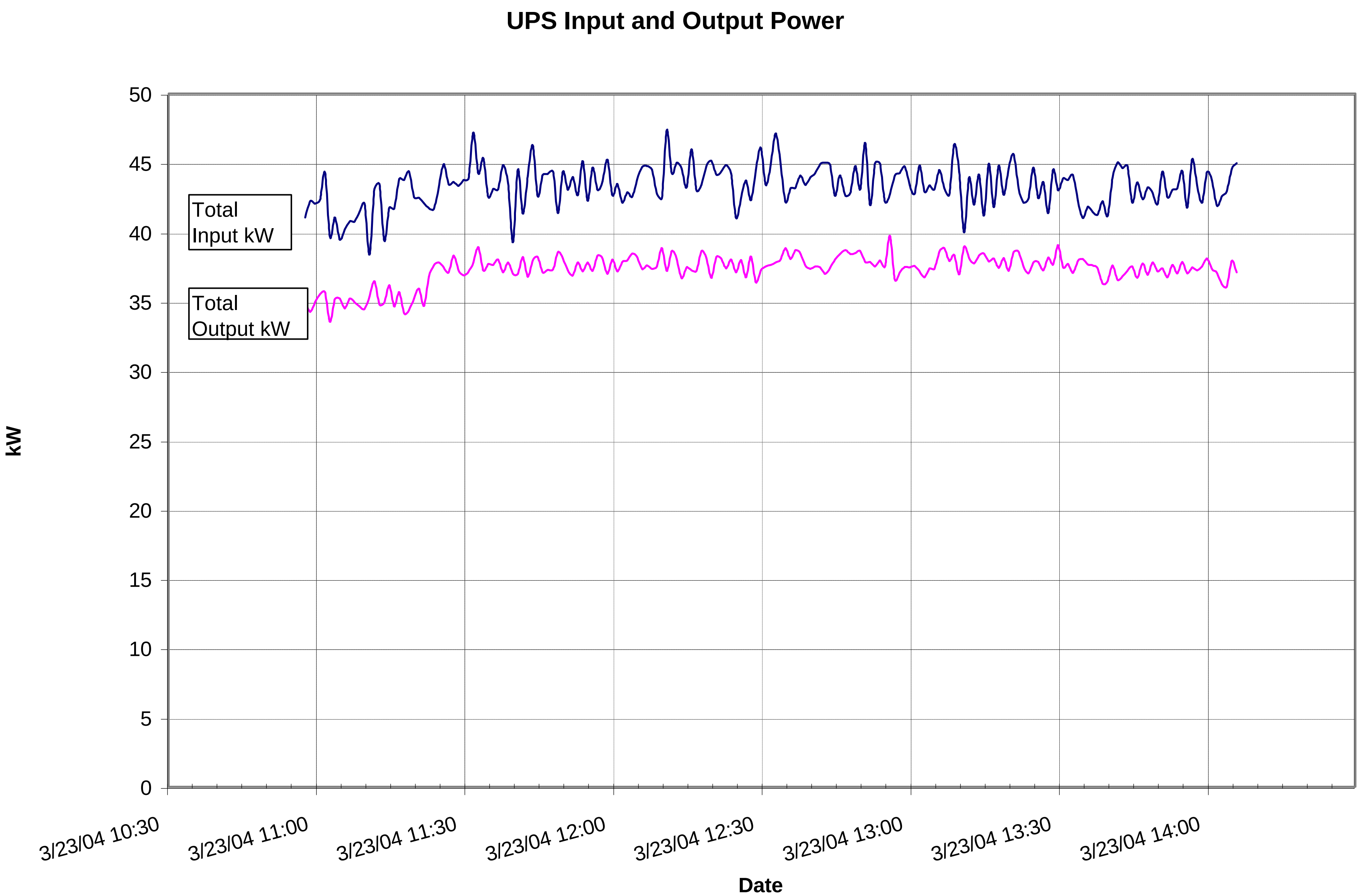


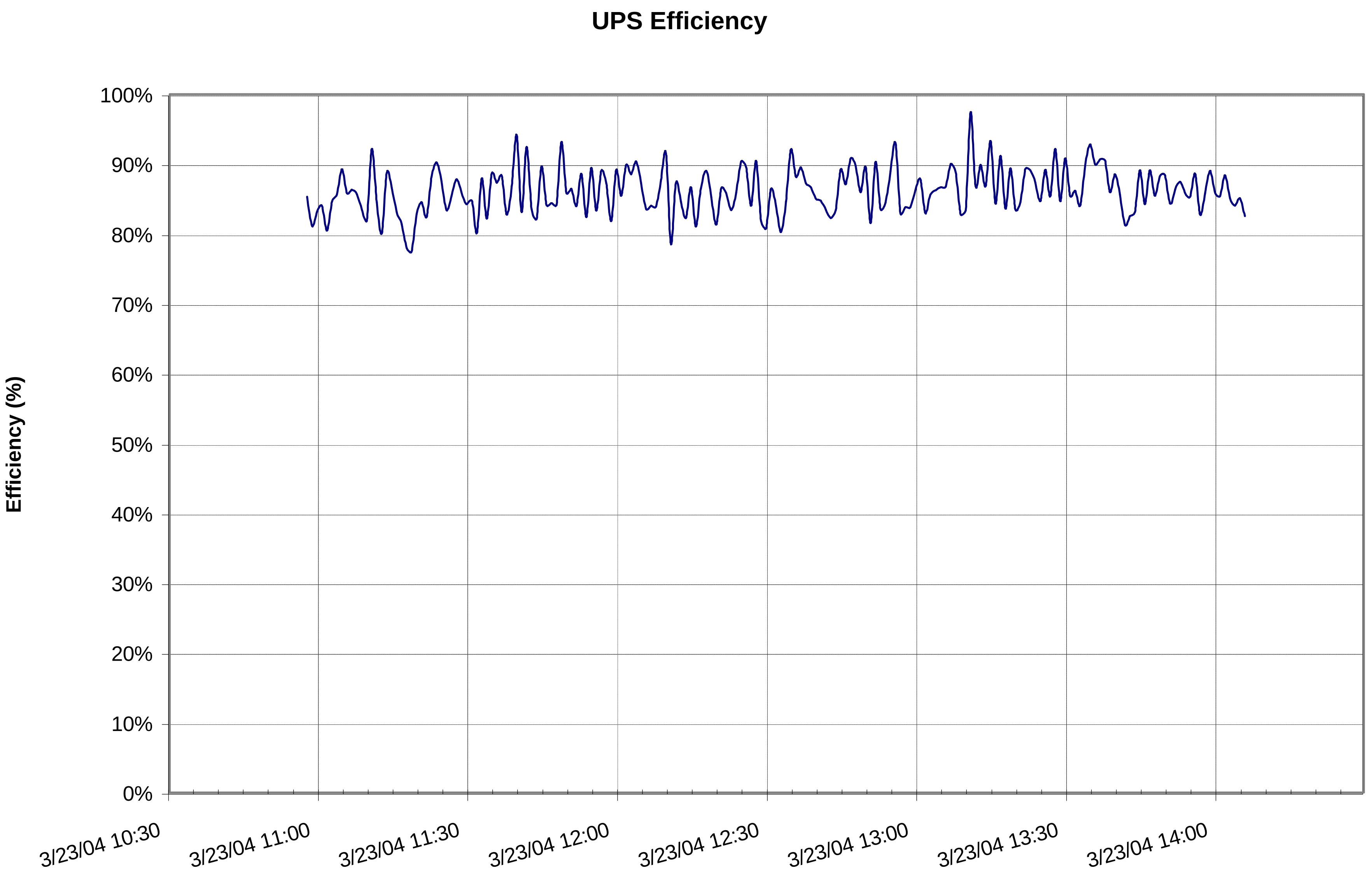
RAH-6 Supply and Return Air Temperatures
Temperature (°F)
100
90
80
70
60
50
40
30
20
10
0
Return
Supply
3/16/04 0:00
3/17/04 0:00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
3/24/04 0:00
Date

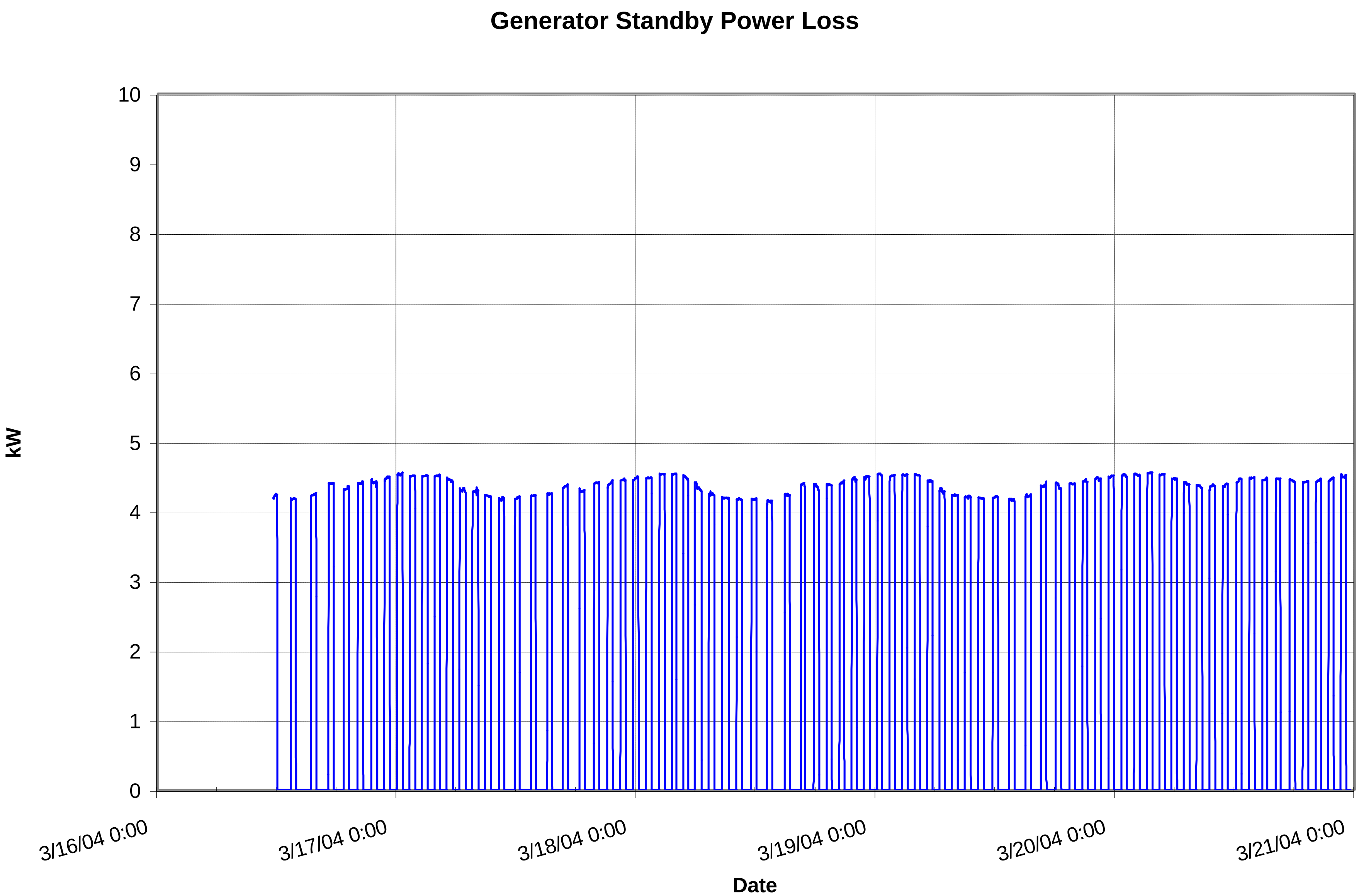


RAH-6 Power
kW
35
30
25
20
15
10
5
0
3/15/04 0:00
3/16/04 0:00
3/17/04 0:00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
3/24/04 0:00
Date

Electrical Systems
UPS & Backup Generator

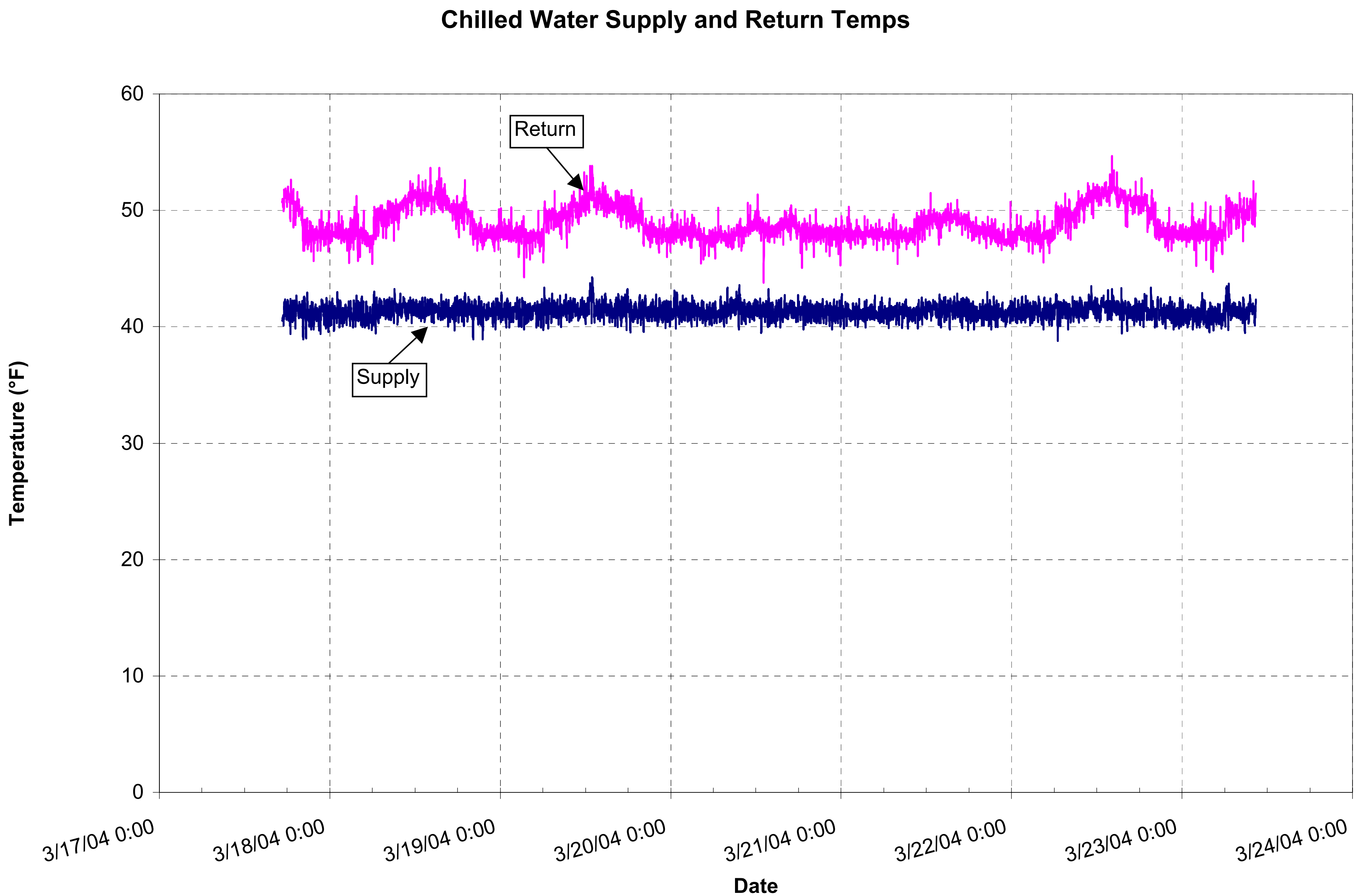

UPS Input and Output Power
kW
Date
Total Input kW
Total Output kW
50
45
40
35
30
25
20
15
10
5
0
3/23/04 10:30
3/23/04 11:00
3/23/04 11:30
3/23/04 12:00
3/23/04 12:30
3/23/04 13:00
3/23/04 13:30
3/23/04 14:00

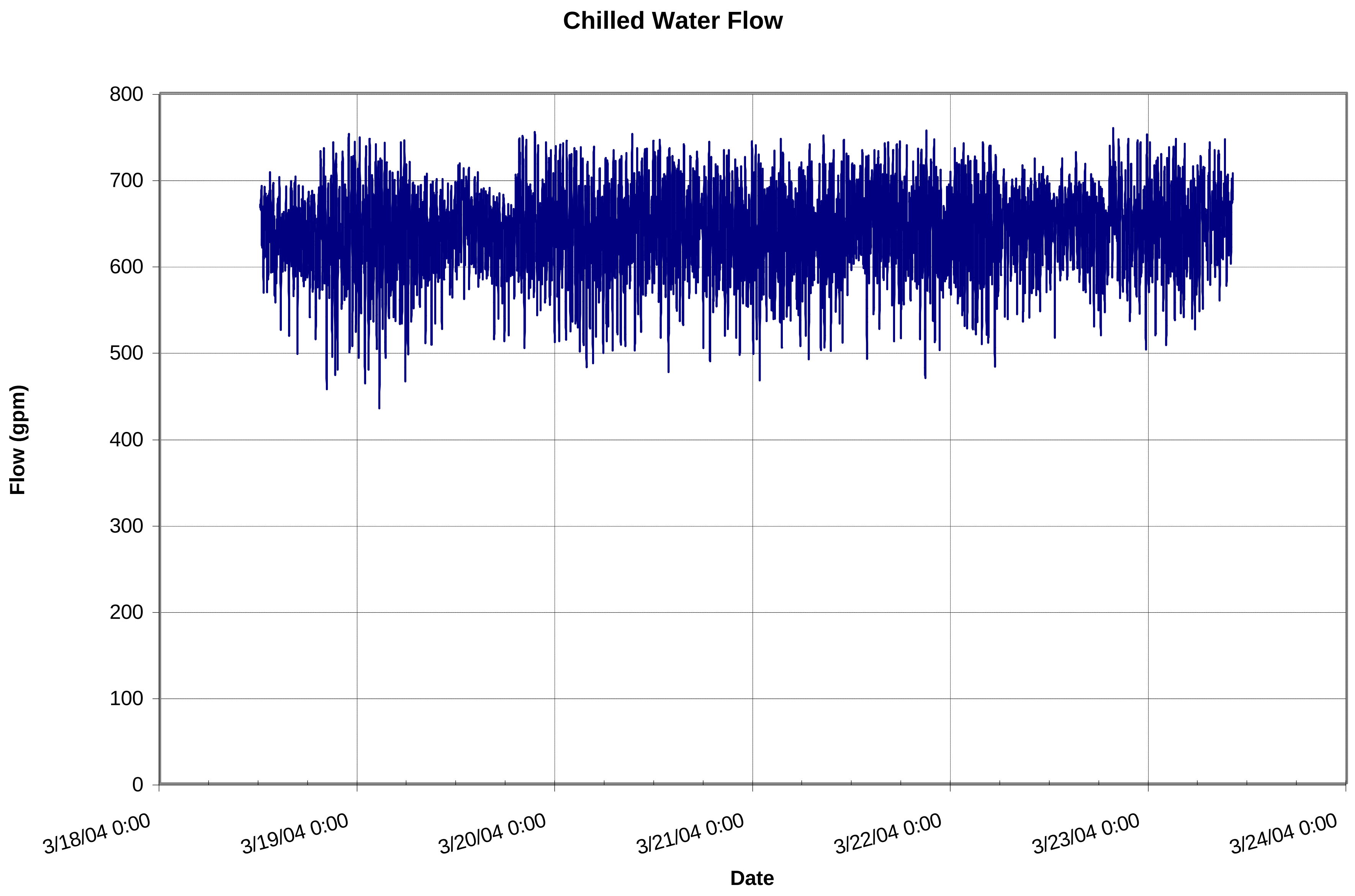

UPS Efficiency
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Efficiency (%)
3/23/04 10:30
3/23/04 11:00
3/23/04 11:30
3/23/04 12:00
3/23/04 12:30
3/23/04 13:00
3/23/04 13:30
3/23/04 14:00
Date

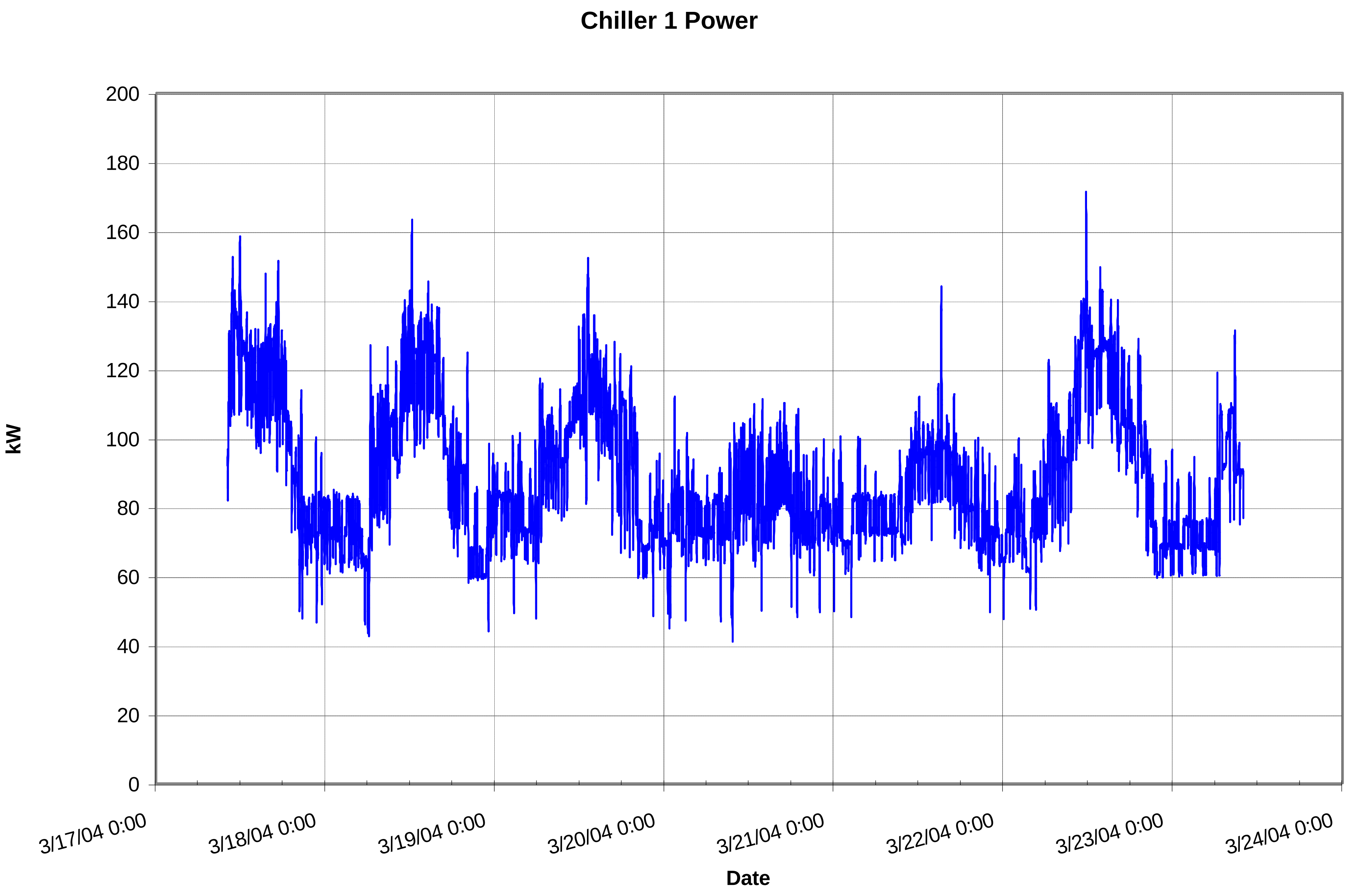


Generator Standby Power Loss
kW
10
9
8
7
6
5
4
3
2
1
0
3/16/04 0:00
3/17/04 0:00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
Date

Chilled Water System

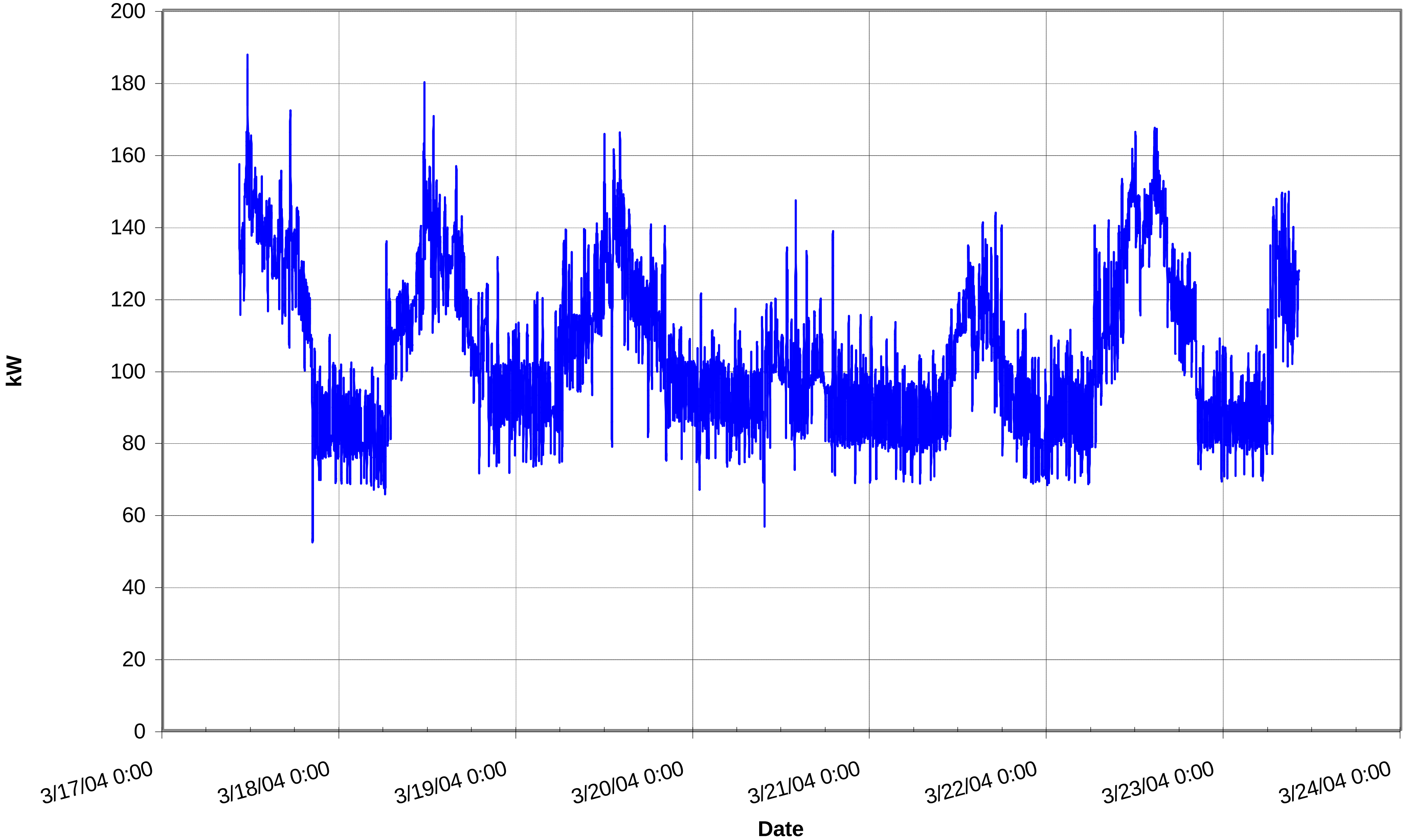

Chilled Water Supply and Return Temps
Return
Supply
Temperature (°F)
60
50
40
30
20
10
0
3/17/04 0:00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
3/24/04 0:00
Date

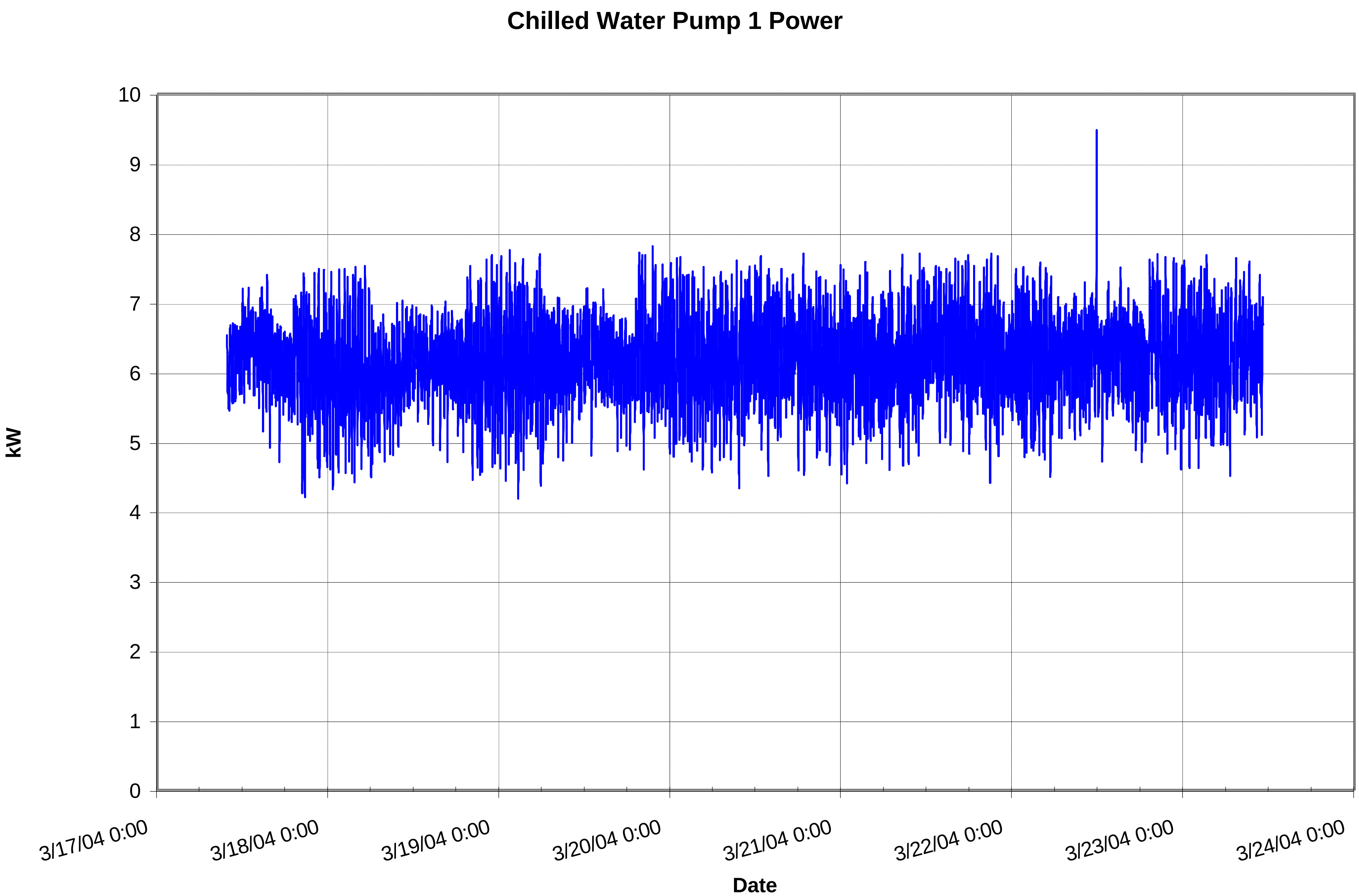

Chilled Water Flow
Flow (gpm)
800
700
600
500
400
300
200
100
0
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
3/24/04 0:00
Date



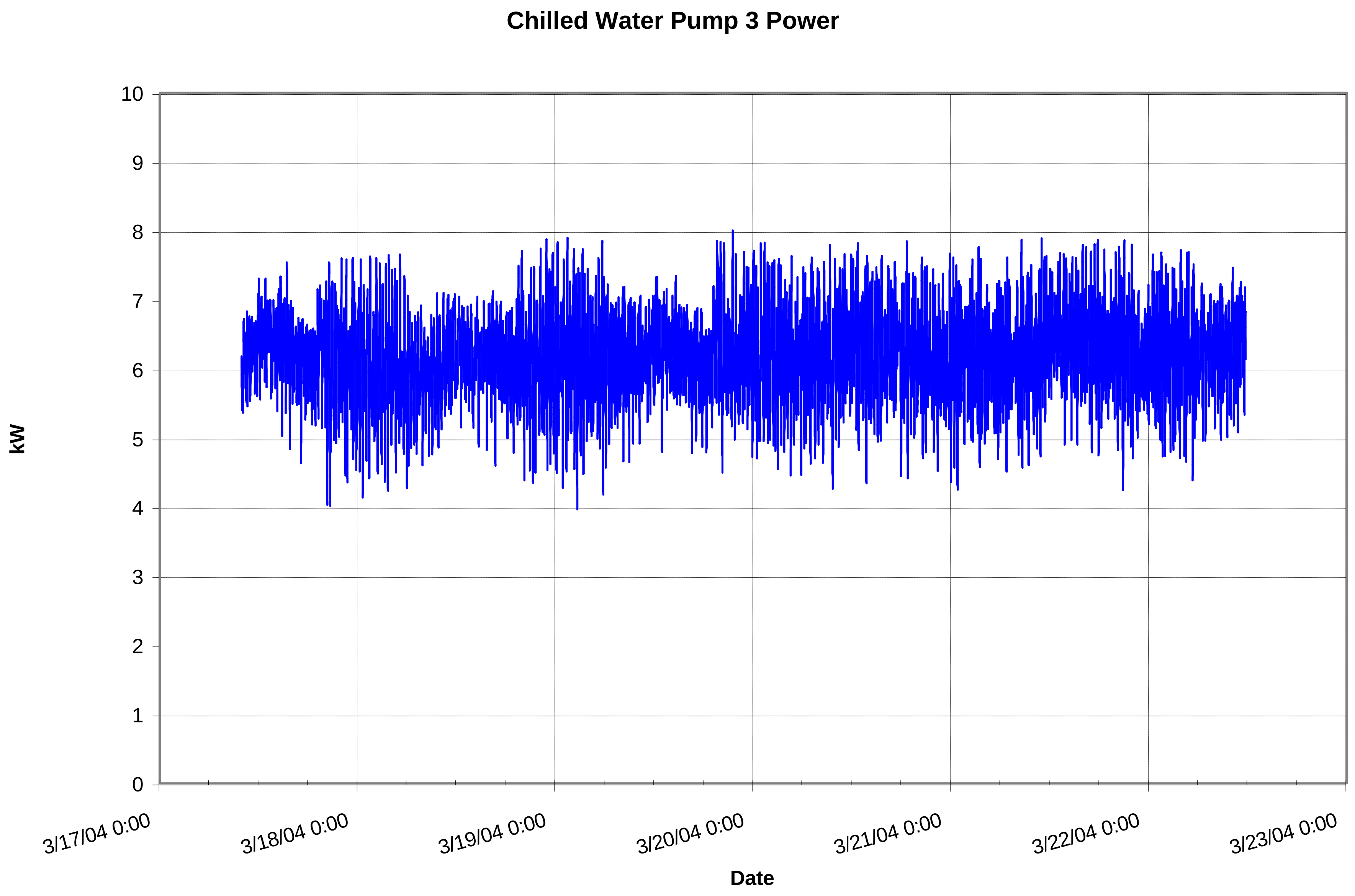
Chiller 1 Power
kW
200
180
160
140
120
100
80
60
40
20
0
3/17/04 0:00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
3/24/04 0:00
Date

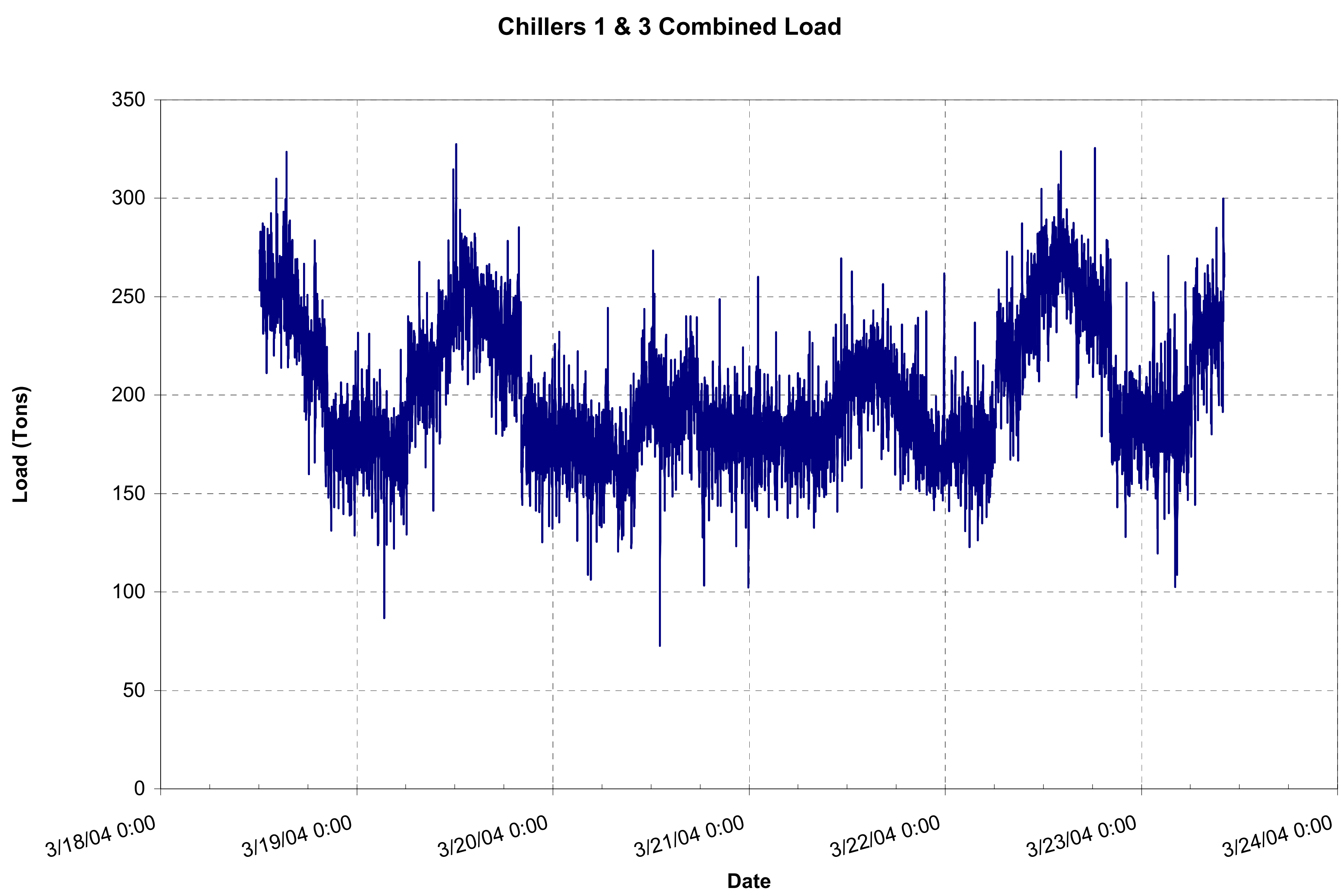
Chiller 3 Power



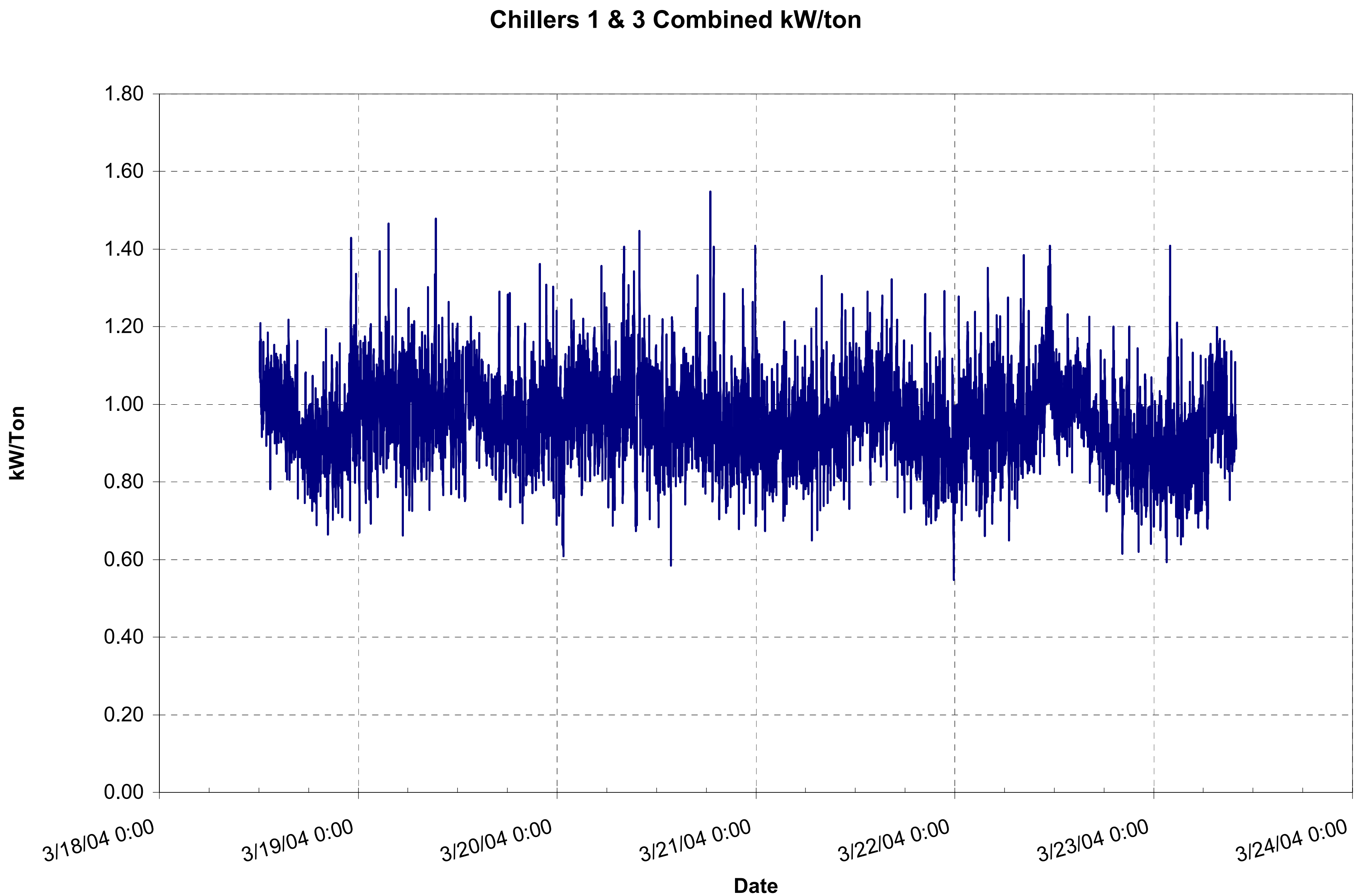


Chilled Water Pump 1 Power
kW
10
9
8
7
6
5
4
3
2
1
0
3/17/04 0:00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
3/24/04 0:00
Date

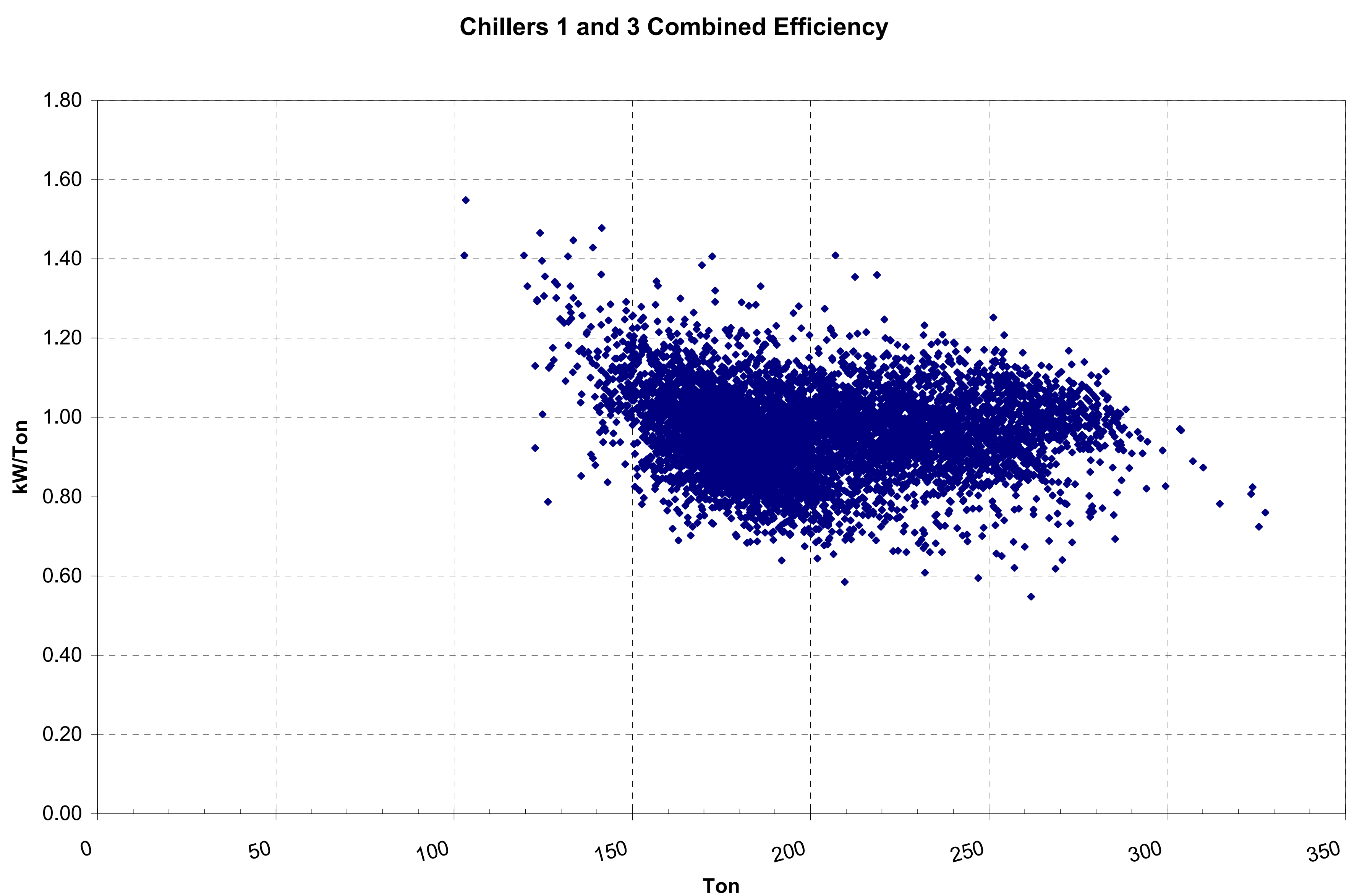

Chilled Water Pump 3 Power
kW
10
9
8
7
6
5
4
3
2
1
0
3/17/04 0:00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
Date

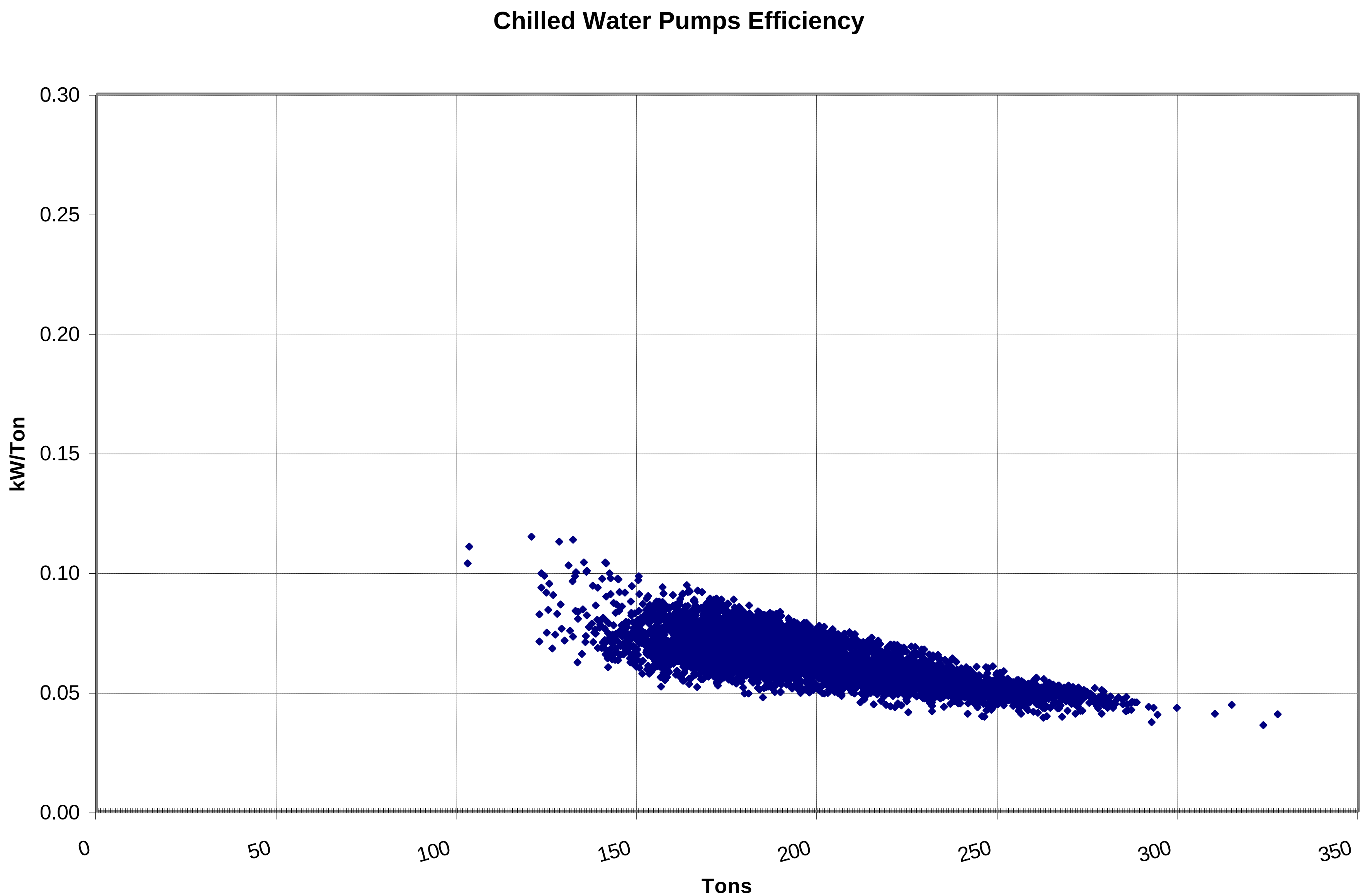


Chillers 1 & 3 Combined Load
Load (Tons)
350
300
250
200
150
100
50
0
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
3/24/04 0:00
Date

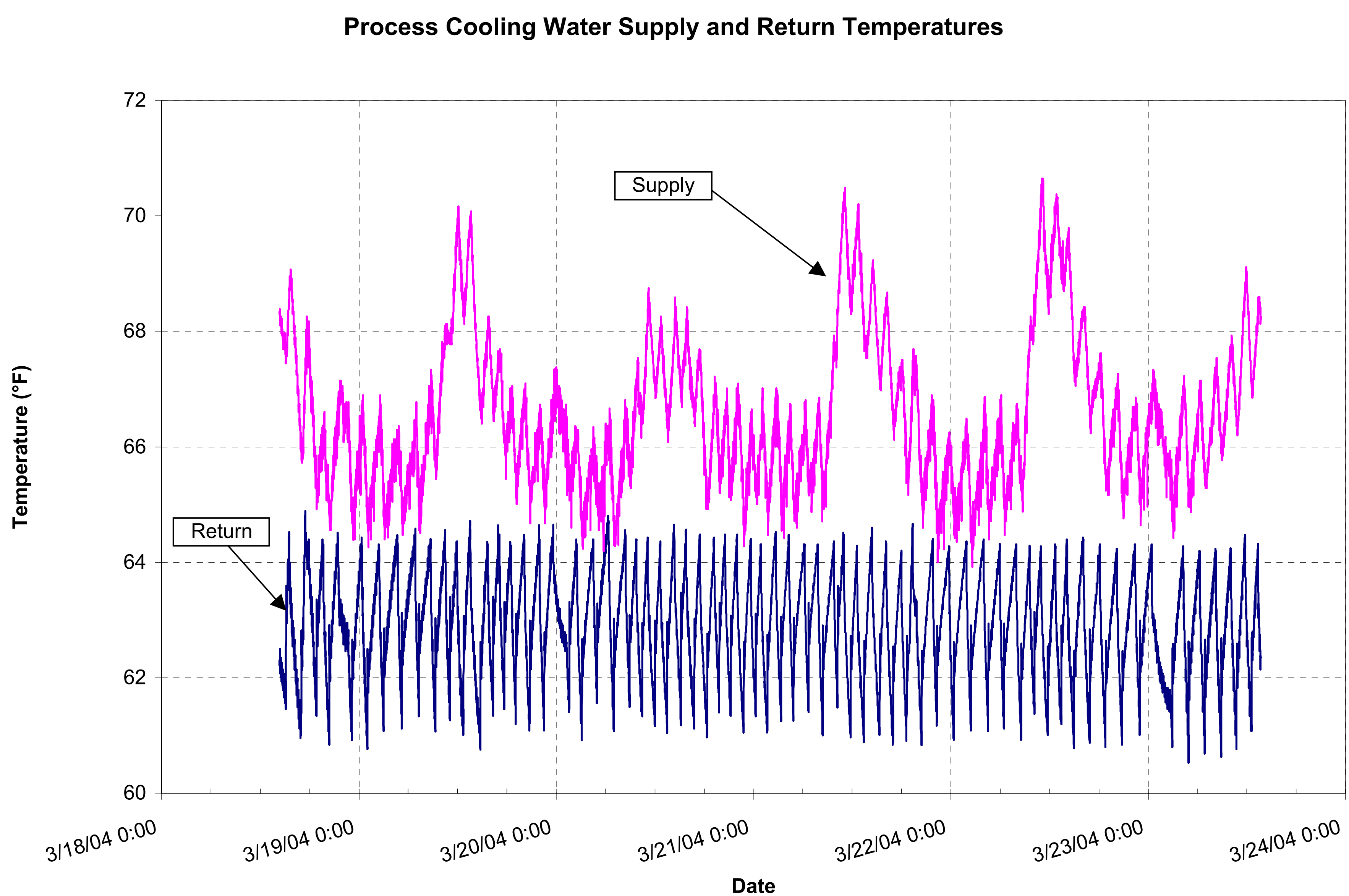


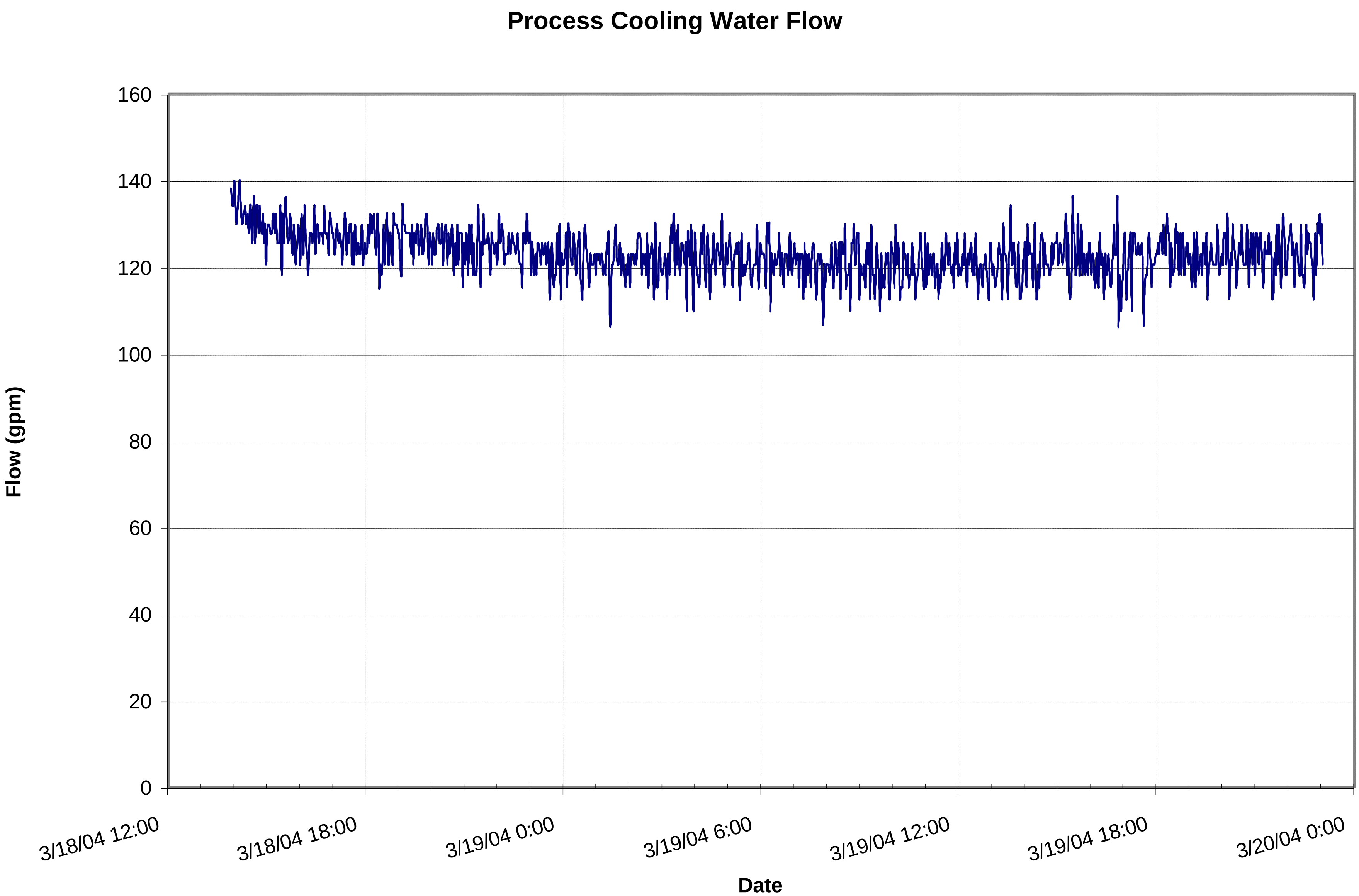
Chillers 1 & 3 Combined kW/ton
kW/Ton
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
3/24/04 0:00
Date


Chillers 1 and 3 Combined Efficiency
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
kW/Ton
0
50
100
150
200
250
300
350
Ton

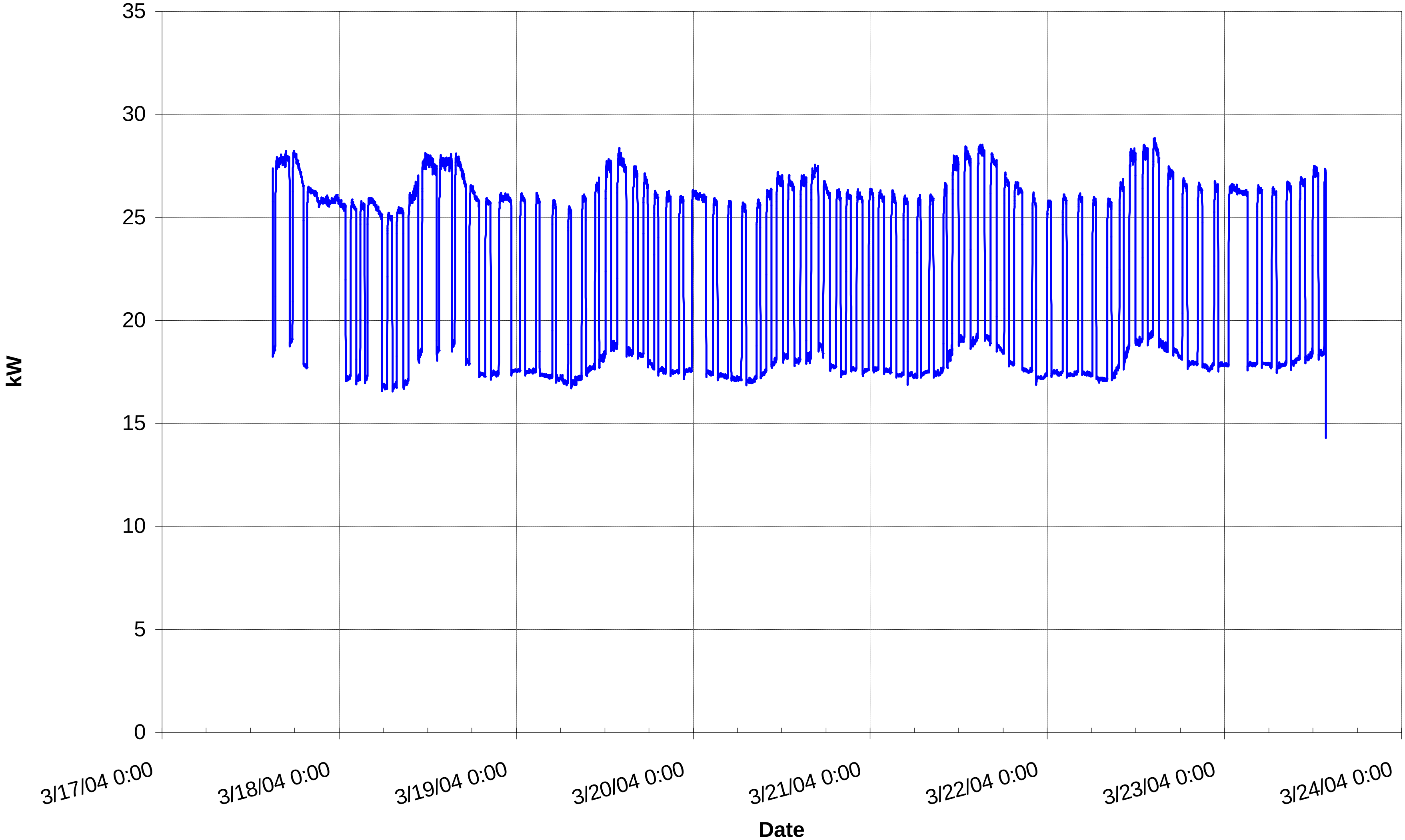

Chilled Water Pumps Efficiency
kW/Ton
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
50
100
150
200
250
300
350
Tons

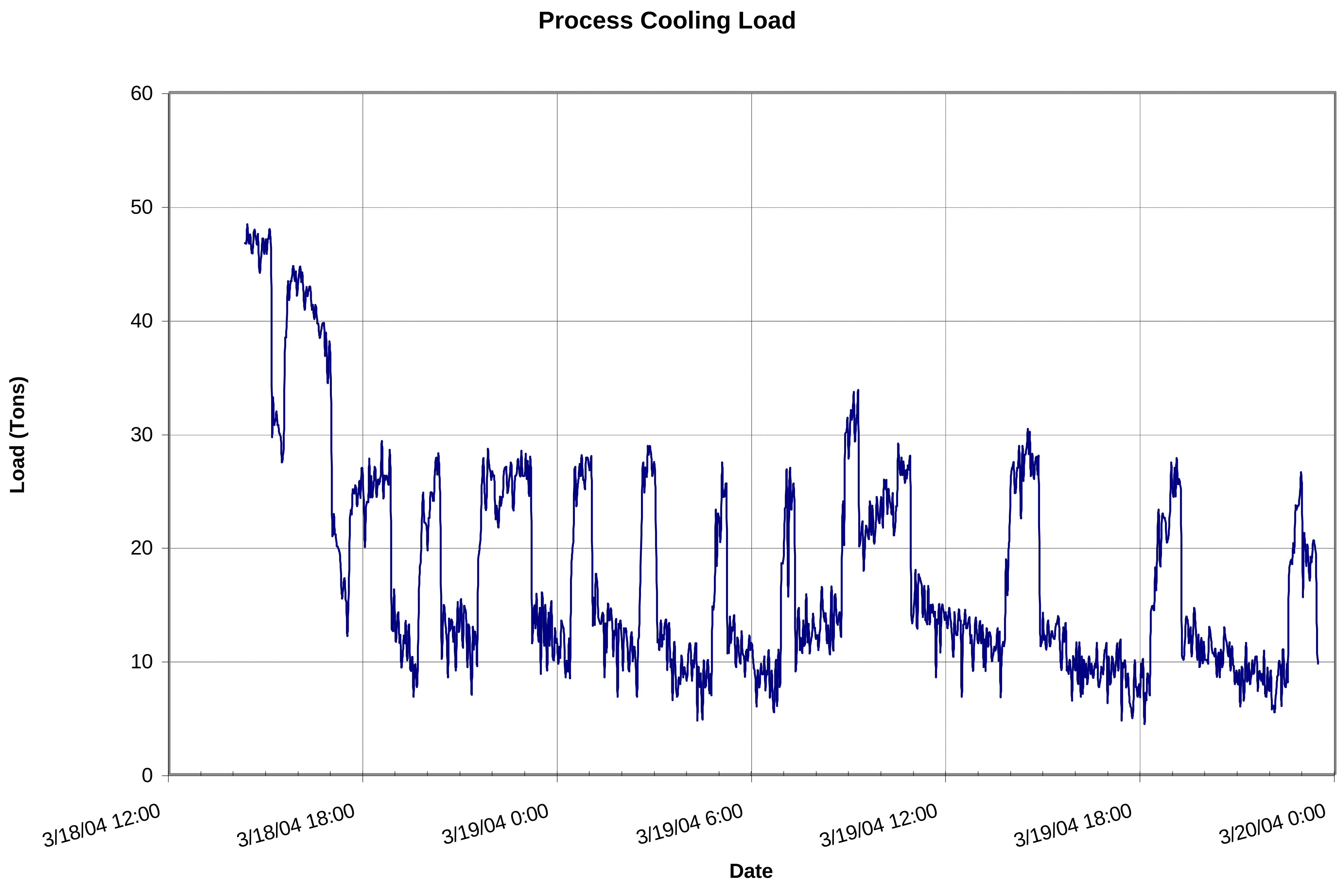
Process Chilled Water System


Process Cooling Water Supply and Return Temperatures
Temperature (°F)
72
70
68
66
64
62
60
Supply
Return
3/18/04 0:00
3/19/04 0:00
3/20/04 0:00
3/21/04 0:00
3/22/04 0:00
3/23/04 0:00
3/24/04 0:00
Date

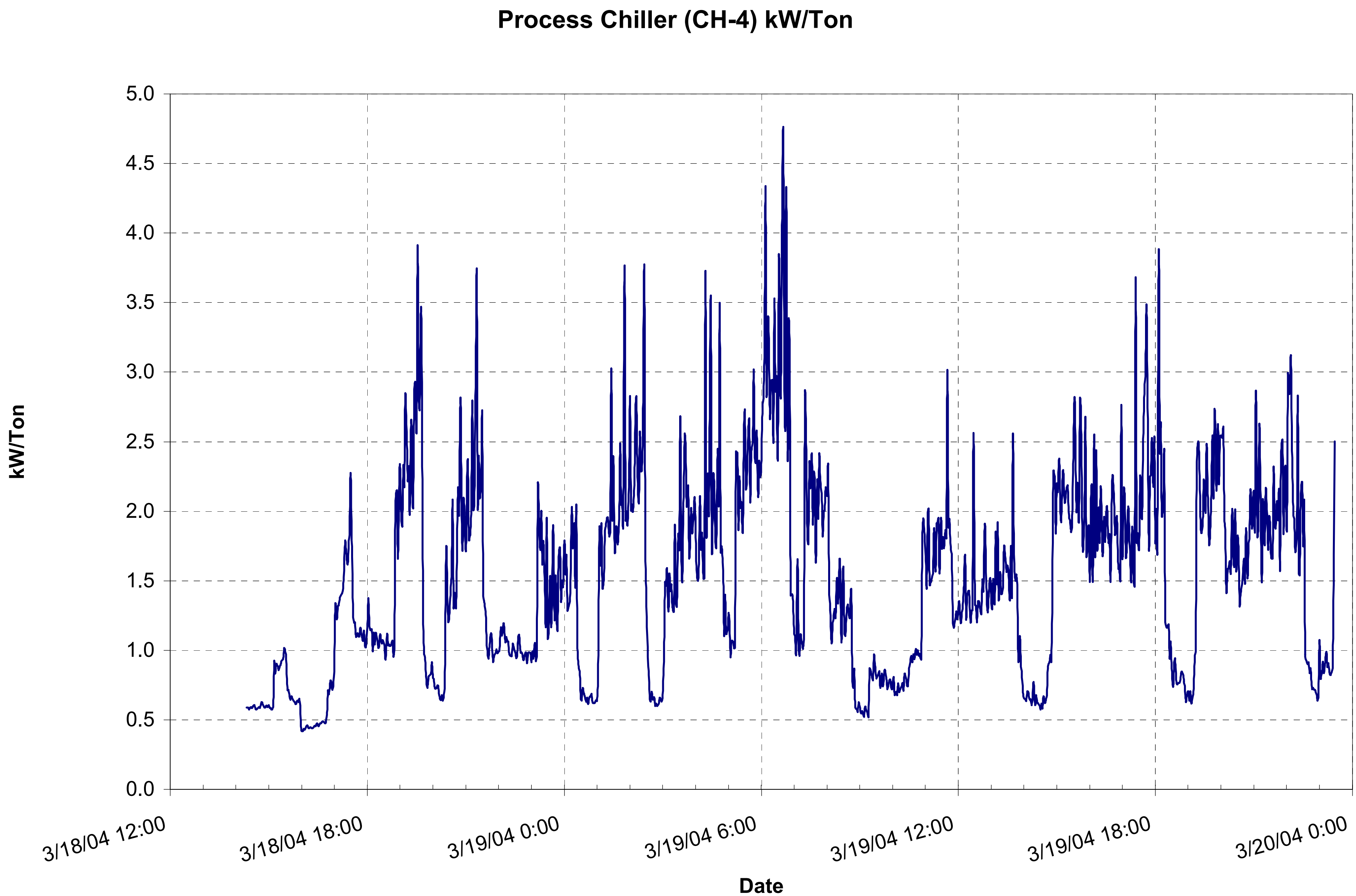

Process Cooling Water Flow
Flow (gpm)
160
140
120
100
80
60
40
20
0
3/18/04 12:00
3/18/04 18:00
3/19/04 0:00
3/19/04 6:00
3/19/04 12:00
3/19/04 18:00
3/20/04 0:00
Date

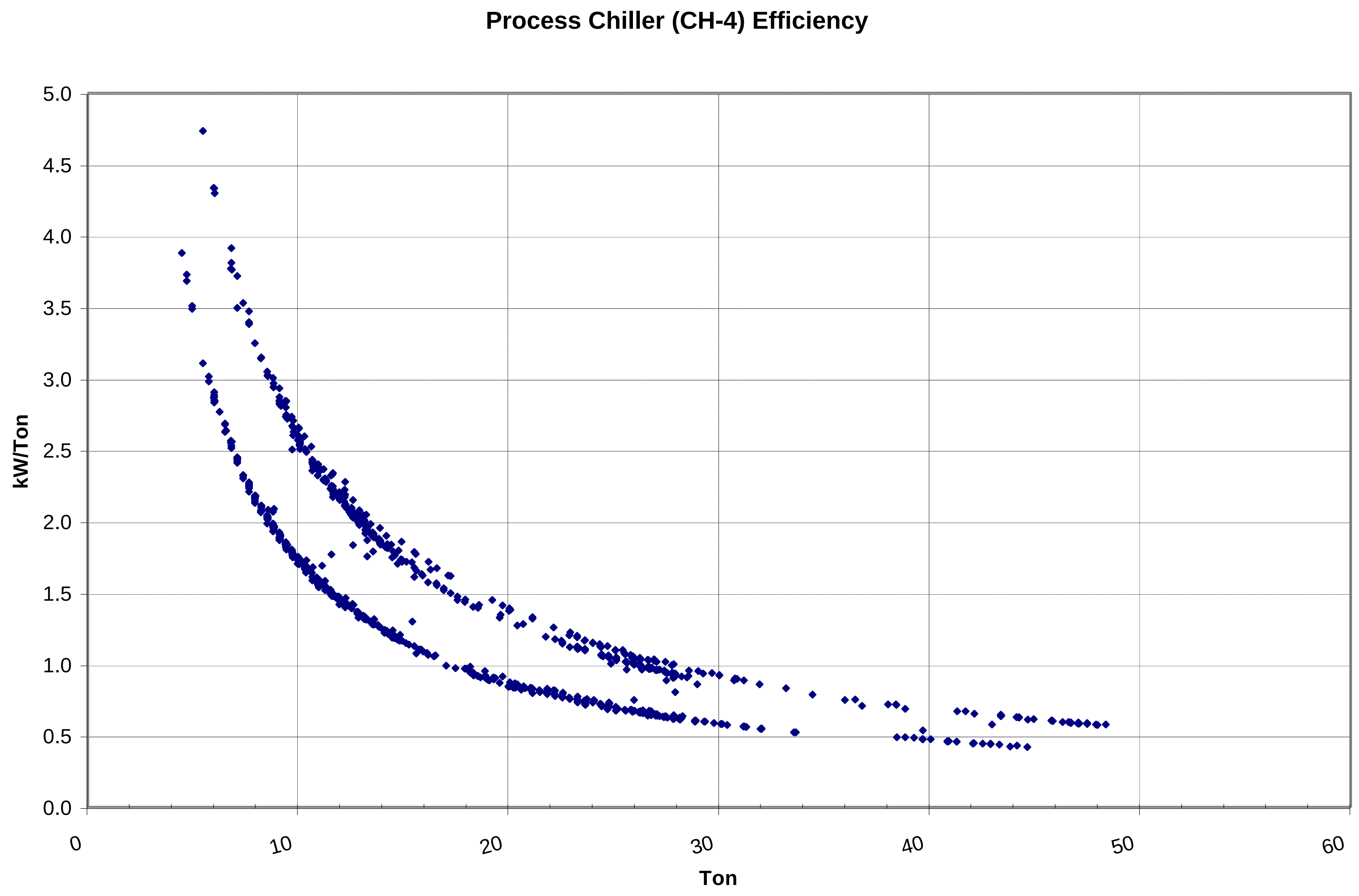
Process Chiller (CH-4) Power





Process Cooling Load
Load (Tons)
60
50
40
30
20
10
0
3/18/04 12:00
3/18/04 18:00
3/19/04 0:00
3/19/04 6:00
3/19/04 12:00
3/19/04 18:00
3/20/04 0:00
Date


Process Chiller (CH-4) kW/Ton
kW/Ton
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
3/18/04 12:00
3/18/04 18:00
3/19/04 0:00
3/19/04 6:00
3/19/04 12:00
3/19/04 18:00
3/20/04 0:00
Date



Process Chiller (CH-4) Efficiency
kW/Ton
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
Ton

Appendix C

Data Collection
and Accuracy Notes

Data Collection and Accuracy Notes

The following notes describe specific measurements and what assumptions were made in preparing calculated results.

Cleanroom Data

Lighting Power	Lighting loads measured directly at their respective breakers.
Process Power	Process tool loads measured directly at their respective breakers.
Average Filter Velocity	Filter velocity based on airflow divided by the assumed effective HEPA filter area of 6.8 square feet.
Primary Cleanroom Area	The area certified at a rated class level. This is taken from the drawings.
Secondary Cleanroom Area	Air return area.

Recirculation Air

Air Flow	All air flow measurements were provided by certification report.
Fan Power	Fan power was measured directly
RCU Efficiency	Number of cubic feet of recirculation air delivered to a given cleanroom, divided by the total kW of the units providing the recirculation air.

Make-Up Air Handling Unit (MUAH)

Air Flow	
Fan Power	Fan power was measured directly.
MUAH Efficiency	Number of cubic feet of air delivered per kW.

Chiller

Total Power	Chiller loads measured directly at their respective breakers.
Total Cooling Supplied	Determined by direct flow and temperature measurements of supply and return chilled water at the common header of the three chillers. Accuracy of this calculation (20%) reflects the uncertainty of the chilled water flow.
Cooling Tons	Standard engineering calculation based on temperature and flow.
Efficiency Metric	Amount of chiller power (kW) per ton of cooling supplied by the chilled water plant.

Pumps

Total Power	Pump loads measured directly at their respective breakers.
Efficiency Metric	Amount of pumping power (kw) per ton of cooling supplied by the chilled water plant.

Utility Billing

Annual Electric Use	Use for the entire site is taken from the most recent complete calendar year (2003) bills as provided.
Annual Electric Cost	Same as above.
Annual Natural Gas Use	Same as above.
Annual Natural Gas Cost	Same as above.

Appendix D

Measurement Methodology

Measurement Methodology

Data collection measurements were made according to the following procedures:

Ultrasonic Flowmeter – Controlotron

- Equipment: Controlotron Uniflow 1010
- Identify straight pipe run.
- Remove pipe insulation
- Clean pipe surface.
- Program flow meter with pipe characteristics.
- Measure wall thickness using thickness gauge.
- Verify meter setup.
- Plug meter into AC outlet.
- Secure transducer rails on pipe.
- Clean transducer surfaces.
- Apply gel to transducers.
- Secure transducers on rails.
- Read real time data. Verify flow conditions.
- Log data.

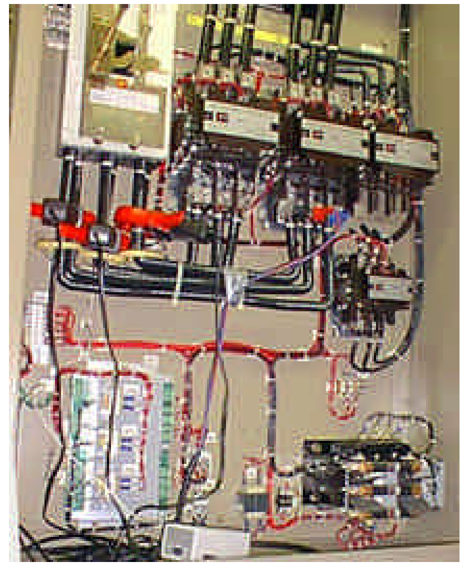
Water Temperature – Pete's Plug

- Equipment: Pace Scientific 4-channel pocket loggers model XR440, and 4" 30kOhm thermistors.
- Attach thermistor temperature sensor to pocket logger channel block.
- Setup pocket logger using product software.
- Verify channels set to correct sensor type and operation.
- Upload setup to pocket logger to launch logging.
- Insert thermistor into Pete's plug.
- Secure pocket logger to pipe.
- Read real time data. Verify setup and actual conditions.
- Log data.

Air Temperature/Relative Humidity – AHUs and Cleanrooms

- Equipment: Pace Scientific 4-channel pocket loggers model XR440, 4" 30kOhm thermistors, or Temperature/Relative Humidity sensors.
- Attach temperature/relative humidity sensor to pocket logger channel block.
- Setup pocket logger using product software.
- Verify channels set to correct sensor type and operation.
- Set RH linear scale specified by the sensor.
- Upload setup into pocket logger to launch logging.
- Read real time data. Verify setup and actual conditions.
- Log data.

Power Trend – Elite Logger



- Equipment: Elite Logger and ELOG 97c software.
- Select current transducers (CTs) appropriate for the measurement and panel space constraints.
- Attach current transducers (CTs) to Elite logger channel block.
- Plug Elite logger into AC supply.
- Setup Elite logger using product software.
- Electrician installation of voltage sensors in the electrical panel.
- Electrician installation of CTs in electrical panel for the specified load to be measured.
- Read real time data.
- Verify balanced current as well as appropriate, balanced voltage readings.
- Secure panel door and attach caution tape and warning notice if panel cannot be locked shut.
- Log data.

Power Spot Measurement – Power Sight

- Equipment: Power Sight PS 3000
- Plug Power Sight into AC supply if necessary.
- Connect current transducers (CTs) and voltage sensors to Power Sight.
- Electrician installation of voltage sensors in the electrical panel.
- Electrician installation of CTs in electrical panel for the specified load to be measured.
- Verify balanced current as well as appropriate, balanced voltage readings.
- Read and record the real time power reading for spot measurement.
- Log data for selected measurements.

Appendix E

CleanRooms Magazine:
“An examination of ACRs: An opportunity to reduce energy and construction costs”

An examination of ACRs: An opportunity to reduce energy and construction costs

Now that cost-cutting has become paramount, it's time to discuss putting the growing list of energy-saving recommendations into practice

By Peter Rumsey PE, CEM

There are several conflicting sets of recommendations on what is the best airflow for cleanrooms. Recent articles in Cleanrooms magazine have explored the different ways of measuring or describing air flows and have discussed the upcoming Institute of Environmental Sciences and Technology (IEST; Rolling Meadows, Ill.) recommended changes; however, few industry observers have examined actual practices and the foreseeable impact on construction and energy costs.[1,2]

A recent benchmarking project conducted by Pacific Gas and Electric Company (San Francisco) and Lawrence Berkeley National Laboratory (Berkeley, Calif.) that measured air change rates in several cleanrooms verified that there is no consistent design strategy for air change rate, even for cleanrooms of the same cleanliness classification. Air change rates per hour (ACRs) are crucial for cleanroom designers because they have a significant impact on fan sizing and energy use.

Using best-practice ACRs can result in clean-filtered air, lower construction costs and reduced energy costs—a win-win situation for cleanroom owners.

Current design recommendations

Today, designers and cleanroom operators have a variety of sources to choose from when looking for an ACR recommendation. There is no clear consensus on what is an optimum ACR, and many of the established guidelines are outdated.

A recent article in Cleanrooms magazine pointed out that many of the recommended ACRs are based on relatively low-efficiency filters that were prevalent 10 years ago.3 For example, today's widely-used 99.99 percent efficient filters are three times more effective at filtering out 0.3 micron particles than the 99.97 percent filters that were common 10 years ago. Ultra-low penetration air (ULPA) filters are even more efficient than those of a decade ago.

When Rumsey Engineers (Oakland, Calif.) conducted a review of recommended cleanroom ACRs, it found that there is no agreement on a correct rate. Most sources suggest a range of rates. These ranges tend to be wide and do not provide clear guidance to designers who need to use a set ACR value to specify fan sizes. Figure 1 shows the result of our comparative review of recommended ACRs.

Air changes affect energy and construction costs

ACRs are the single largest factor in cleanroom fan sizing, building configuration and energy costs. As shown in Figure 1, recommended rates can vary from 250 to more than 700 air changes per hour for an ISO Class 5 cleanroom.

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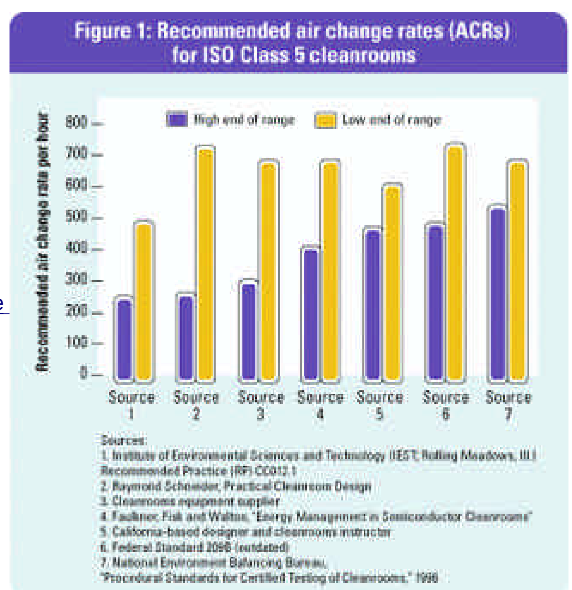


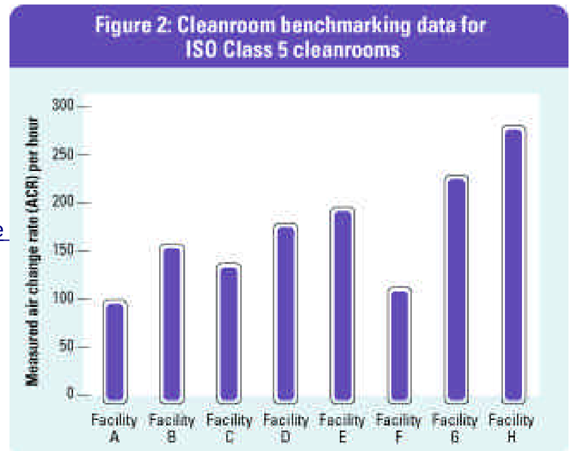
After gathering the results from its comparative review of recommended ACRs, Rumsey Engineers discovered that recommended rates for ISO Class 5 cleanrooms vary widely from source to source.

The high end of that range is almost three times the rate at the low end, yet the impact of this difference on fan sizing and motor horsepower is radically greater. According to the fan affinity laws, the power difference is close to the cube of the flow or air change rate difference. For example, a 50 percent reduction in flow will result in up to a factor of eight, or 87.5 percent reduction in fan power. Due to filter dynamics, the cube law does not apply exactly and, typically, the reduction is between a cube and a square relationship.

Even relatively conservative reductions of 10 percent to 20 percent in ACR provide significant benefits. A 20 percent decrease in ACR will enable close to a 50 percent reduction in fan size, with reduction calculation: 1 - 80%3. The energy savings opportunities are comparable to the potential fan size reductions.

While energy costs are not high on the priority list during the design and construction of cleanrooms, capital costs or construction costs are always important. Not so long ago, electronics, pharmaceutical and biotechnology companies did not need to worry much about construction costs. Currently, however, any designer would be irresponsible if construction costs or energy costs were ignored.

Click here to enlarge image



According to the results of the Pacific Gas and Electric Company and Lawrence Berkeley National Laboratory benchmarking data, cleanroom operators can use ACRs that are lower than what is recommended practice for ISO Class 5 facilities.

It's a common assumption that making a cleanroom more efficient will drive up construction costs, which is often impossible in today's tight-fisted climate. However, well-planned ACR reductions can reduce both construction and energy costs. This is that elusive goal, a true win-win situation, which decreases the amount of work the mechanical system has to perform and offers high leverage for downsizing equipment.

Current practice

Pacific Gas and Electric Company and Lawrence Berkeley National Laboratory recently conducted a cleanroom energy benchmarking study.4 A variety of systems and practices were measured, including air change rates in eight ISO Class 5 cleanrooms. The results were surprising.

While the recommended design ranges for ACRs are from 250 to 700 air changes per hour, the actual operating ACRs ranged from 90 to 250 (see Figure 2). All of these cleanrooms were certified and performing at ISO Class 5 conditions. This shows that cleanroom operators can use ACRs that are far lower than what is recommended practice without compromising either production or cleanliness requirements.

This is often done to lower energy costs. However, these facilities did not take advantage of the fan sizing reduction opportunities during construction. As a result, most of the fan systems were operating at very low variable speed drive speeds.

What others have found

Air cleanliness is a critical component of any cleanroom, far outweighing energy saving priorities. Designers and operators need evidence from others who have tried similar strategies in order to address the perceived risks of lowering air change rates.

Fortunately, a growing body of data, case studies and research are available that document success. In a recent study by International Sematech (Austin, Texas), no noticeable increase of particle generation was found when air change rates were lowered by 20 percent in ISO Class 4 cleanrooms.5 A recent study at the Massachusetts Institute of Technology (MIT; Cambridge, Mass.) found that in a raised-floor-type cleanroom "with a small decrease in air velocity, such facilities will decrease particle deposition and maintain air unidirectionality."6

Other successes have been noted by cleanroom operators at Intel (Santa Clara, Calif.) and Sandia National Laboratories (Albuquerque, N.M.). Michael Dever, Intel's Oregon site utility manager, reported that an Intel project aiming to reduce both air change rates and ceiling HEPA velocities succeeded in achieving a 20 percent fan energy savings goal at a low cost of implementation. Sandia National Laboratories has also successfully reduced air change rates in their state-of-the-art ISO Class 4 and 5 cleanrooms. This is especially significant because Sandia pioneered laminar flow cleanrooms in the early 1960s.

Conclusions and recommendations

There is no doubt that more clarification and justification of optimal and safe air change rates are required. From the Pacific Gas and Electric Company and Lawrence Berkeley National Laboratory benchmarking data, it is clear that air change rates can be lower than what is currently recommended by several sources.

The benchmarking data suggests that an ISO Class 5 facility should be designed with an air change rate of around 200 air changes per hour. A conservative upper limit should be about 300, significantly lower than the high range of 700 indicated by some sources.

Facility designers and operators tend to err on the side of conservatism in their efforts to provide high reliability cleanroom support. More independent research on optimized air change rates based on contemporary filter efficiencies needs to be conducted to reduce the perceived risks of modifying standard practices.

Biotechnology and pharmaceutical cleanrooms are currently designed to meet current good manufacturing practices (cGMPs) that require high air change rates. These ACRs should be re-examined as part of upcoming revisions to the cGMP. In addition, IEST recommended practices updates should include lower ACR guidelines.

Using better air change rate practices will allow designers to offer lower construction costs as well as reduced energy costs while maintaining the high level of air cleanliness that is required in cleanroom facilities.III

***Peter Rumsey PE**, CEM, president of Rumsey Engineers (Oakland, Calif.), specializes in cleanroom design and other critical applications. He has over 20 years of experience internationally in commercial, governmental and scientific projects. Rumsey can be reached at prumsey@rumseyengineers.com.*

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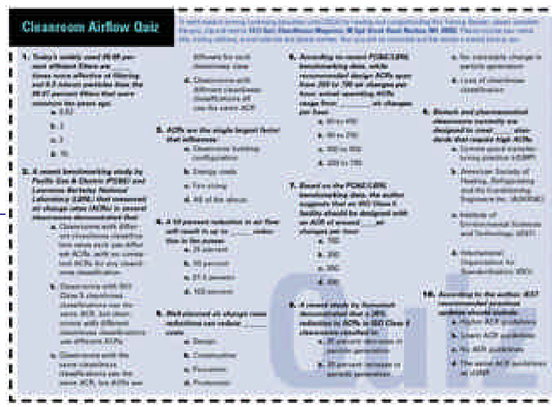

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